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GEOGRAPHY, GEOLOGY, AND MINERAL RESOURCES OF THE PORTNEUF QUADRANGLE, IDAHO

BY

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CONTENTS

ILLUSTRATIONS

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By George Rogers Mansfield

ABSTRACT

In this report the interesting history of the Portneuf quadrangle is briefly sketched and its geographic features are systematically described. About half of the area is a much eroded mountainous upland whose ridges trend northwest and have a maximum altitude of about 7,300 feet, the remainder forming broad lowlands 1,000 to 2,000 feet lower. The climate is semiarid, with an average rainfall ranging from 13.88 inches at Pocatello to 17.26 inches at Blackfoot Dam.

The geologic formations include representatives of all the Paleozoic and later systems except the Jurassic, Cretaceous, and early and middle parts of the Tertiary. These are systematically described. The rocks are folded and broken and have a noticeable tendency toward eastward inclination or overturning, a common structural habit of the general region. Many of the structural features are concealed or obscured by a widespread blanket of Tertiary rocks, but they are described in such detail as is practicable. A noteworthy structural feature is the occurrence of a window in the Bannock overthrust where the uparched thrust plane has been cut through by the erosion of the upper fault block. The geologic history is briefly outlined.

The mineral resources of the quadrangle are phosphate rock, which is the most valuable, limestone, road metal, building stone, and quartzite. Phosphate is discussed both in connection with the description of seven individual townships and in some of its broader relations. All these resources, which are treated in the order named, are present in sufficient quantity to supply more than any probable local need over a long period. Water resources are described in the final chapter. Surface waters are insufficient for irrigation within the quadrangle, because under the present plan of utilization much of the available supply is distributed outside. Ground water is apparently abundant, but as yet is little utilized. The opportunities for power development within the quadrangle are not promising.

INTRODUCTION

SCOPE OF THE WORK

The study of the Portneuf quadrangle, Idaho, is one of a series which the United States Geological Survey has planned for the Rocky Mountain region in the general vicinity of the Idaho-Wyoming border. Detailed examination has revealed the fact that this region contains tremendously thick accumulations of sedimentary rocks, geologic structure of great complexity, igneous rocks in considerable volume and some variety, and mineral resources of great value.

The work previously accomplished in this region, chiefly under the direction of the writer, comprises the mapping of the Fort Hall Indian Reservation, with an area of about 800 square miles, and of the Cranes Flat, Henry, Lanes Creek, Freedom, Slug Creek, Crow Creek, and Montpelier quadrangles, which together have an area of about 2,200 square miles, a total of 3,000 square miles. In addition the Randolph quadrangle, Utah, which adjoins the Montpelier quadrangle on the south and has an area of 892 square miles, has been mapped by G. B. Richardson. The writer has also made reconnaissance studies of areas in the Willow Creek, Pine Creek, and Teton Basin districts and on the Continental Divide in Idaho and the Salt River Range in Wyoming. Official reports covering various phases of the work and a number of scientific papers relating to the region have already been published. The Fort Hall Indian Reservation is the subject of a separate bulletin,[1] and the area of the seven designated quadrangles in Idaho is described in detail in a professional paper of the Geological Survey.[2]

As much of the country supposed to contain valuable phosphates has not been mapped, it has been thought worth while to continue the detailed mapping of areal units, not only for the sake of outlining and determining the character of the phosphate reserves but also to supply a basis for broader regional studies which it is hoped may shed additional light upon the history and development of the Rocky Mountains.

A fairly complete bibliography of the subjects covered by this report is given in the professional paper above referred to (see also Professional Paper 56), so that a bibliographic list in this bulletin is unnecessary.

LOCATION AND AREA OF THE QUADRANGLE

The Portneuf quadrangle is in southeastern Idaho between meridians 111° 45′ and 112° west longitude and parallels 42° 45′ and 43° north latitude and comprises about 219 square miles. Its west edge is about 23 miles due east of Pocatello, with which it has con-

[1] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho, with a chapter on water resources by W. B. Heroy: U. S. Geol. Survey Bull. 713, 1920.

[2] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 1927.

nections by road and by rail, but as these routes have to follow the windings of Portneuf Canyon distances along them are nearly three times as great as air lines.

The quadrangle includes in the northwestern part a strip about 6 miles long and 3 miles wide belonging to the Fort Hall Indian Reservation, which was mapped by a Geological Survey party in charge of the writer in 1913. On the east it is adjoined by the Henry quadrangle, which, with six other quadrangles on the north, east, and southeast, was mapped in the same way in 1916 and earlier years. The Portneuf quadrangle thus serves as a connecting link between two previously surveyed areas and helps to provide a continuous geologic section from the Snake River Plains of southern Idaho eastward to the ranges of western Wyoming. (See fig. 1 and pl. 1.)

FIELD WORK

The topographic control work was done by L. F. Briggs and F. L. Whaley and the topographic mapping by C. G. Anderson and J. L. Lewis, all of the Geological Survey, in 1914. In 1913 T. 5 S. and part of T. 6 S., R. 38 E., were mapped geologically as part of the Fort Hall Indian Reservation, and in 1916 T. 5 S., R. 40 E., with some adjacent territory, was mapped by the writer and P. V. Roundy in connection with the survey of the Henry and Cranes Flat quadrangles. In 1923 the writer, assisted by H. C. Mansfield and later by W. B. Lang, spent two months reviewing portions of the previously mapped areas and completing the geologic mapping of the Portneuf quadrangle. Later in the season they carried the work forward into the Paradise Valley quadrangle, on the north. In 1925 parts of two days were spent measuring the Paleozoic section north of Monroe Canyon and examining the beds north and south of Tenmile Pass.

HISTORICAL NOTES

The Portneuf quadrangle lies in an area important as hunting and trapping grounds to the Indians, trappers, and earlier explorers. As general accounts of the early history of the region have been given elsewhere,[3] only a few supplemental notes need be added here. The name Portneuf, which has come down from early days, is that of one of the trappers.

In the discussion of the Fort Hall Indian Reservation the writer noted the activities of Captain Bonneville in the region of Snake and Portneuf Rivers and expressed the opinion that Bonneville

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[3] Mansfield, G. R., Geography of southeastern Idaho: Assoc. Am. Geographers Annals, vol. 15, No. 2, pp. 51–64, 1925. See also U. S. Geol. Survey Bull. 713, pp. 12–14, 1920; Prof. Paper 152, pp. 2–5, 1927.

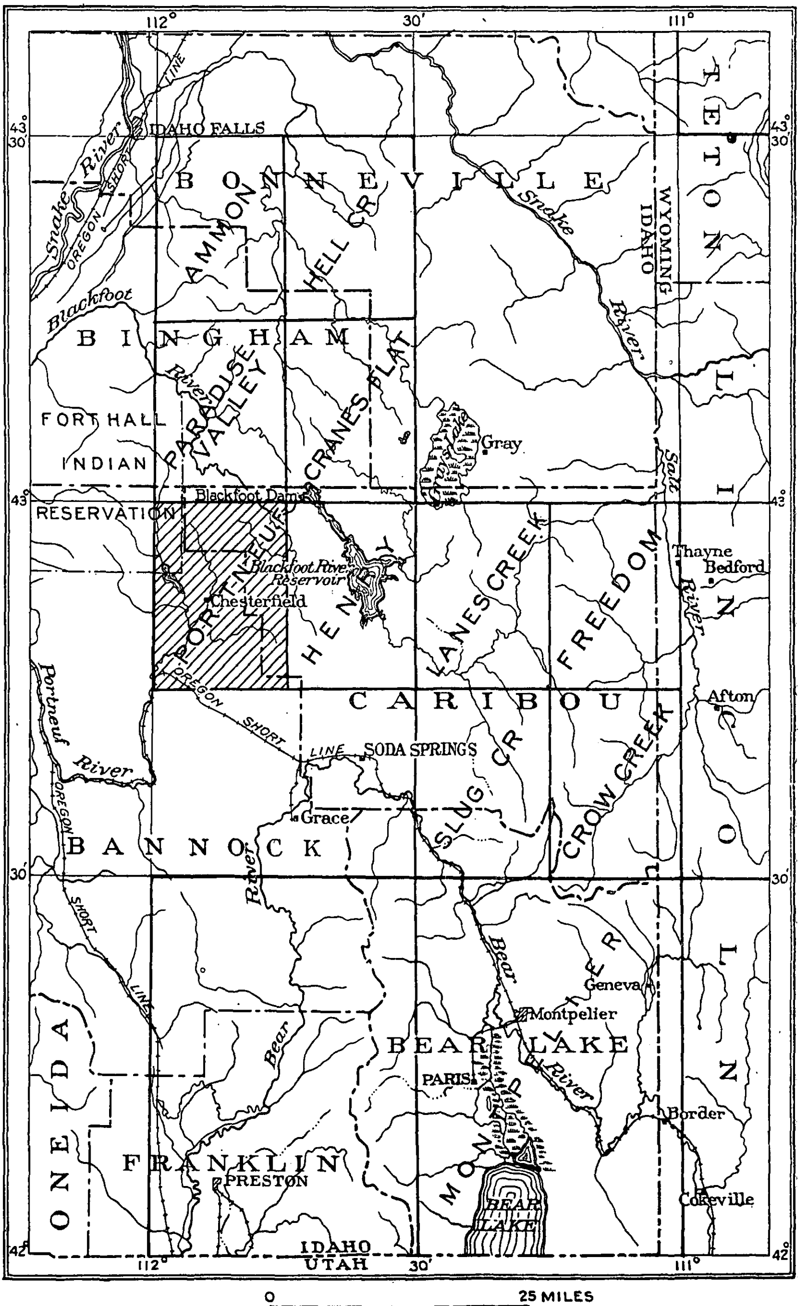

FIGURE 1.—Index map showing the position of the Portneuf quadrangle with reference to previously surveyed areas

wintered near the large springs on the Snake River flat within the reservation at the heads of Clear Creek and Spring Creek. Irving[4] quotes the captain as saying that the springs where he wintered "gush out of the earth in sufficient quantity to turn a mill and furnish beautiful streams, clear as crystal and full of trout of large size." So far as size and character are concerned Bonneville's description would certainly apply to the springs mentioned. In talking about the matter with H. Van Slooten, of Bancroft, however, the writer learned that local opinion favored the springs in secs. 29 and 30, T. 7 S., R. 39 E., as the probable site of Bonneville's winter camp. Upon a review of Irving's account the geographic setting there given was seen to fit the upper Portneuf region somewhat better than the lower Portneuf. It is quite probable that the last-named springs were the actual site of Bonneville's camp and that Portneuf Valley was the scene of some of his hunting exploits.

Portneuf Valley and Portneuf Canyon were traversed by the Astorians on their way to the mouth of Columbia River. Irving[5] gives a vivid description of their journey with its hardships and of the life and habits of the Indians and trappers whom they met. Nathaniel J. Wyeth, a trader from Boston and the founder of Fort Hall, came here in 1834, joining Bonneville in buffalo hunting on the upper Blackfoot, and J. C. Frémont in 1843 passed through this region in connection with his explorations farther west.

The old emigrant trail to Snake and Columbia Rivers crossed Portneuf Valley and wound along Portneuf Canyon. This route was later selected by a transcontinental railroad and now constitutes part of a great artery of interstate commerce.

THE HAYDEN SURVEYS

The earliest geologic descriptions of the region that include the Portneuf quadrangle were given by members of the Hayden survey. In 1871 a party under Hayden traveled northward through Cache Valley and along Marsh Creek and the lower Portneuf on the way to the Yellowstone Park area. The next autumn the same party, returning from the field, came through the upper Portneuf Valley to the bend of Bear River and proceeded along Bear River and Bear Lake to Evanston, where the party disbanded. Geologic observations along the route are recorded in the Fifth Annual Report of the Hayden Survey, published in 1872, but few of them apply directly to the Portneuf quadrangle.

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[4] Irving, Washington, The adventures of Captain Bonneville, U. S. A., in the Rocky Mountains and the Far West, Pawnee ed., vol. 1, pp. 324–325, 1898.

[5] Irving, Washington, Astoria, 1836.

In 1872 the Snake River division of the Hayden survey, with Frank H. Bradley as geologist, passed northward from Ogden through Malade Valley and down the Portneuf to Snake River. The party went up Ross Fork to Fort Hall, which was then situated in the valley of Lincoln Creek, and thence northward and northeastward into the Teton Range, the Yellowstone country, and the headwaters of Snake River. On the return the party again visited Fort Hall and spent a number of days exploring the region of the divides between Ross Fork, the Portneuf, and Lincoln Valley. (See the Sixth Annual Report, published in 1873.)

In 1877 the Green River division of the Hayden survey, A. C. Peale, geologist, completed a geologic map that includes the area of the Portneuf quadrangle. Peale's report, in the Eleventh Annual Report, published in 1879, contains brief descriptions of parts of the area, but his party covered so large a territory that he could devote little time or space to this particular area. His map, which shows valuable generalizations, nevertheless requires considerable correction, as will be noted in later pages.

LATER GEOLOGIC WORK

The east side of the Portneuf quadrangle was included in a reconnaissance by Schultz and Richards[6] in 1911. Their work covered principally Tps. 5, 6, and 7 S., R. 40 E., with a little adjacent territory on the west and south. They noted the general relations of the Carboniferous and Triassic rocks in those townships and obtained some structural data, to which further reference will be made. The subsequent activities of the Geological Survey in the quadrangle have been mentioned under the heading "Field work."

GEOGRAPHY

SUMMARY OF REGIONAL PHYSIOGRAPHIC DEVELOPMENT

In a previous report[7] the writer has given an extended geographic account of the general region that includes the Portneuf quadrangle. It is shown there that the country has a complex erosional history, including many stages, the more recent of which are given for reference in the following table, though not all of them are represented in the Portneuf quadrangle. The stages recognized in an earlier and less comprehensive study of the Fort Hall Indian Reservation are also cited for comparison.

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[6] Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267–284, 1913.

[7] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 1927.

Erosional stages in southeastern Idaho

Epoch	Professional Paper 152, 1927	Bulletin 713, 1920
Recent.	Postglacial.	Spring Creek.
Pleistocene.	Blackfoot cycle (St. Charles glacial episode).	Gibson.
	Dry Fork.	Putnam.
	Elk Valley.	
Pliocene.	Gannett.	
	Deposition of Salt Lake formation.	
Miocene.	Tygee cycle?	
	Middle Miocene deformation.	
Eocene.	Snowdrift peneplain.	

The Snowdrift peneplain is not represented within the quadrangle, but some remnants may exist in the higher parts of the Portneuf Mountains in the west and southwest, not yet studied except in earlier reconnaissance surveys. Middle Miocene deformation is supposed to have permitted the erosion (Tygee cycle?) that carved the valleys and low hills that were subsequently blanketed by the Salt Lake formation. The Gannett erosion surface is possibly represented by the even-topped limestone ridge southwest of Sawmill and Graves Creeks in Tps. 5 and 6 S., R. 39 E., and southeastward. Elsewhere the country has been too much worn down to preserve it. The remaining cycles are well represented and correspond as indicated to those previously described in the Fort Hall Indian Reservation. Within the limits of the quadrangle, however, there is no direct evidence of glaciation.

PRINCIPAL TOPOGRAPHIC UNITS

The Portneuf quadrangle includes parts of five mountain ranges and of two intermontane valleys so arranged that the northeast half is chiefly mountains and the southwest half chiefly lowlands. The mountains are principally strike ridges with northwesterly trend and with maximum altitudes of about 7,300 feet above sea level. The older rock structure, however, is largely concealed by later beds, which upon erosion have produced smoothly rounded surfaces that are now cut by early mature canyons with a maximum depth exceeding 1,200 feet. The lowlands are young plains in part basalt-covered and 5,300 feet or more in altitude. The principal topographic units of the quadrangle from northeast to southwest are the Blackfoot Mountains, Blackfoot Valley, Chesterfield Range and Soda Springs Hills, Portneuf Valley, and Portneuf Mountains.

Blackfoot Mountains.—The Blackfoot Mountains as defined by the writer[8] extend northwestward nearly 30 miles from Wilson Creek and Blackfoot River, in the southwestern part of the Cranes Flat quadrangle, and they are about 15 miles in greatest breadth just north of the Paradise Valley quadrangle. The group as a whole is relatively low, rising 600 feet above Willow Creek on the northeast and 1,400 feet above Blackfoot Valley on the southwest. Recent geologic and physiographic work in the Paradise Valley and Ammon quadrangles shows that they agree in topographic development with other mountains of similar altitude in the general region, such as the Chesterfield Range. The drainage goes chiefly to Blackfoot River, but some goes into Willow Creek or other tributaries of Snake River.

Only the extreme southwestern part of the Blackfoot Mountains, comprising perhaps 3 square miles, enters the Portneuf quadrangle, but the group occupies much of the Paradise Valley quadrangle, on the north. Rich phosphate deposits occur in these mountains, but they are not exposed within the Portneuf quadrangle, although they are present within minable depth.

Blackfoot Valley.—Blackfoot Valley, which in the adjacent Henry and Cranes Flat quadrangles maintains a width of 6 miles or more, becomes constricted to less than a mile in width in the northeastern part of the Portneuf quadrangle. It is undoubtedly underlain by basalt, which is more or less overspread by wind-blown or alluvial deposits. The basalt is an extension of the Blackfoot lava field, which forms a prominent topographic feature of the Henry and Cranes Flat quadrangles. Blackfoot Valley is a young basaltic plain in which ledges appear here and there at the surface and as practically continuous cliffs along the stream courses. Its altitude is about 6,100 feet. Its tributary, Corral Valley, has the same character.

Grizzly and Thompson Creeks, which are tributary to the Blackfoot system through Corral Creek, have alluviated valleys that are now submaturely dissected.

Chesterfield Range.—The principal mountain mass in the Portneuf quadrangle has been named by the writer[9] the Chesterfield Range, from the town of Chesterfield, at its southwestern base. The range as a whole is nearly 25 miles long and 10 miles wide. It extends northwestward from Tenmile Pass, in the southeast corner of the quadrangle, to the broad sag west of Morgan, in the southwest-

[8] Op. cit. (Prof. Paper 152), p. 34.
[9] Idem, p. 35.

ern part of the Paradise Valley quadrangle. It is the northern part of the mountain group called by Peale[10] the Soda Springs Hills, but its topographic and geologic isolation make a separate designation more appropriate.

The range is described by Peale as "somewhat plateaulike," but it is composed of several ridges of sedimentary rocks that reach maximum altitudes of about 7,300 feet and rise about 1,000 to 1,200 feet above the valleys on the east but nearly 2,000 feet above the floor of Portneuf Valley on the west. A prominent sedimentary ridge in the southwestern part of T. 7 S., R. 40 E., is shown in Plate 3, *A*. The plateaulike character noted by Peale is with little doubt due to the preservation of the Elk Valley and Dry Fork erosion surfaces. The relationship of these erosion surfaces is well shown near the forks of Eighteenmile Creek, in secs. 3, 4, 9, 10, and 15, T. 7 S., R. 40 E. The ridge top in secs. 3, 10, and 15, corresponding with neighboring ridge tops though not so high as some of them, is assigned to the Elk Valley erosion surface. The row of projecting spurs at the west and southwest comprises the remnants of an old valley floor of Dry Fork age now cut by youthful and early mature valleys of the Blackfoot cycle. (See pl. 3, *C*.) Near the end of the Blackfoot cycle or after it the lower course of Eighteenmile Creek became obstructed by the development of a large travertine terrace across the mouth of its canyon. This terrace stands about 100 feet above the adjacent slopes with its upper 50 feet an almost sheer cliff. A similar obstruction has formed at the mouth of Little Flat Canyon, about a mile and a half to the southeast. (See pl. 3, *B*.) Above these terraces young alluvial plains have been formed.

The alluviation stage, which was a late feature of the Blackfoot cycle and is represented throughout the region by valley fillings and alluvial fans, was succeeded by an epoch of moister climate probably associated with the last glacial stage. During this moister epoch the alluviated areas were in places submaturely dissected, the remnants of the former surfaces being preserved as flats or gentle slopes at corresponding heights above the later valley floors. The town of Chesterfield stands upon such a remnant or terrace 50 feet or more above the valley of Twentyfourmile Creek, which lies on the east side of the town. The terrace here rises 126 feet in 0.9 mile, as indicated by two bench marks. About 100 feet higher than this terrace is another similar terrace developed locally near the mouth of Twentyfourmile Canyon, probably recording a substage in the Blackfoot cycle. (See pl. 4, *A*.) Similar terraces or substages have been noted elsewhere in the general region.

[10] Peale, A. C., Report of the Green River Division: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., p. 596, 1879.

The Chesterfield Range supports some timber, and parts of it are utilized for grazing. Ranches are scattered here and there at favorable places. Phosphate beds occur in several areas more fully described on pages 69 to 89.

Soda Springs Hills.—The group of rocky hills here called the Soda Springs Hills constitutes the southern member of the group to which Peale gave this name. It lies southeast of the Chesterfield Range and extends from Tenmile Pass to the bend of Bear River west of Soda Springs, a distance of about 10 miles. These hills have not been mapped or studied in detail. Only the northern tip of the group, composed of older limestones, enters the quadrangle.

Portneuf Valley.—The lowland called Portneuf Valley occupies perhaps a third of the quadrangle. It is very narrow at the northwest corner, but it broadens at first slowly and then rapidly southeastward and attains a width of nearly 10 miles where it crosses the south boundary. The valley is bordered here and there, as at the mouths of Twentyfourmile and Eighteenmile Creeks, with submaturely dissected alluvial fans. The southern part of the valley is a young basalt plain with somewhat uneven surface and with a general altitude between 5,400 and 5,500 feet. The basalt appears at the surface at many places, but elsewhere it is covered with a mantle of wind-blown soil or alluvium thick enough to be generally cultivated. The northern part of the valley is a young alluvial plain, from a few feet to 100 feet lower than the southern part, and is somewhat marshy in the vicinity of Portneuf River. A marshy area in T. 6 S., R. 38 E., has been converted into a reservoir by damming the river. In secs. 23, 25, and 26, T. 7 S., R. 38 E., the flood plain of the Portneuf is bordered by bluffs 15 to 20 feet high. Elsewhere its borders are less clearly defined.

Portneuf Valley is continuous southward with the portion of Bear River Valley that lies west of the Bear River Range, but the drainage of the two valleys is separated by a low divide.

Portneuf Mountains.—As defined by the writer[11] the Portneuf Mountains extend from the north end of Cache Valley to the valley of Blackfoot River in the Fort Hall Indian Reservation. They lie between a bend of Portneuf Canyon, extended southward by Marsh Valley, on the west, and Portneuf and Bear River Valleys, on the east. Portneuf River cuts a gorge across them midway of their length.

The Portneuf Mountains have not been studied in detail, though parts of them have been described in connection with the Fort Hall Indian Reservation.[12] They are high enough in places to preserve parts of the Gannett erosion surface and possibly even remnants of

[11] Op. cit. (Prof. Paper 152), p. 37.
[12] U. S. Geol. Survey Bull. 713, pp. 71–104, 1920.

the Snowdrift peneplain. The later erosion surfaces are undoubtedly represented. Their higher parts support some good timber, but they are principally utilized for grazing. Mineral prospects have been opened in them here and there, and some ore has been shipped,[13] but the outlook for any substantial mineral development, aside from that of the phosphate deposits in their northern part, is poor.

The western part of the Portneuf quadrangle contains some of the eastern foothills of the northern part of the Portneuf Mountains, comprising interstream ridges and spurs and some isolated knobs.

DRAINAGE

Rivers.—Most of the drainage of the quadrangle is tributary to Blackfoot and Portneuf Rivers, though Tenmile Creek, which crosses the southeast corner, belongs to the Bear River system. This creek is intermittent within the Portneuf quadrangle. The Chesterfield Range is the principal divide and is so situated that probably two-thirds of all the drainage goes to the Portneuf. The streams are mostly in a youthful or submature stage, except that in the larger alluviated valleys there are graded reaches in which the streams have the sluggish and winding courses that are characteristic of topographic old age.

Blackfoot River, which makes only a short loop into the northeast corner of the quadrangle, is one of the principal tributaries of Snake River in this region. Its flow is described on page 99. Its principal tributaries, parts of whose courses are within the quadrangle, are Corral and Graves Creeks. Grizzly Creek, which is joined by Thompson Creek, is tributary to Corral Creek, and Sunday and Warbonnet Creeks are tributary to Graves Creek. Except the lower course of Sunday Creek these are all permanent streams. Warbonnet Creek heads against Twentyfourmile Creek and is followed part way by the road from Chesterfield to the Austin ranch and beyond.

Portneuf River (see p. 100) is also directly tributary to the Snake and in its middle and lower courses is comparable to the Blackfoot in size, but in this quadrangle, above the springs in secs. 19 and 30, T. 7 S., R. 39 E., it is small, sluggish, and winding and is bordered here and there by marshy areas.

Although several permanent streams rise in the Chesterfield Range and are ultimately tributary to the Portneuf drainage system, few of them join the Portneuf as surface streams. Most of their water is diverted for irrigation, and the rest sinks into the alluvium or beneath the basalt. The principal tributaries on the east side of the

[13] U. S. Geol. Survey Bull. 713, p. 116, 1920.

valley are Monroe and Little Flat Canyons and Eighteenmile, Moses, and Twentyfourmile Creeks. The reservoirs on Twentyfourmile Creek shown on the map have been practically abandoned, though the larger one still had some water in 1923.

On the west side of the valley Topons Creek is the largest tributary. Smith Creek and King Creek are permanent streams, though their waters are diverted and do not ordinarily reach the river directly.

Springs.—Many springs are distributed over the quadrangle, some of which formerly deposited calcium carbonate in large amounts (see p. 103) and still deposit some. Mention may be made of those on Grizzly and Twentyfourmile Creeks and those along Portneuf River from sec. 19, T. 7 S., R. 39 E., southwestward, all of which give rise to considerable streams. These last-mentioned springs probably have historic interest in connection with the activities of Captain Bonneville in the early days of western exploration.

CLIMATE

A somewhat extended discussion of the climate of southeastern Idaho has already been published,[14] from which the following data pertinent to the quadrangle are abstracted.

Climatic data bearing on Portneuf quadrangle, Idaho

Station	Precipitation, mean annual (inches)	Average number of days having precipitation of 0.01 inch or more	Annual snowfall unmelted (inches)	Temperature (°F.)			Direction of prevailing wind	Length of growing season (days)
				Highest average annual	Lowest average annual	Mean annual		
Blackfoot Dam	17.26	66	81.1	96	−42	37.8	SW.	48
Chesterfield	13.74	68	52.8	99	−48	40.0	W.	65
Fort Hall	9.81	76	28.1	100	−28	45.4	SW.	121
Pocatello	13.88	93	45.0	102	−20	47.5	SE.	158
Southeastern Idaho	13.96	77	62.4	99.2	−38.0	41.1	SW.	87

The data for Pocatello and for southeastern Idaho as a whole are more reliable than those for the other three stations named, one of which covers a period of only 4 to 6 years, whereas the Pocatello record covers about 21 years and the figures for southeastern Idaho comprise observations at 16 stations from Border (Bear River Valley) and Bedford (Star Valley) on the east to Idaho Falls on the west, some of which at the time of compilation (1926) had records covering periods of 25 years.

[14] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 37–44, 1927; Climate of southeastern Idaho: Assoc. Am. Geographers Annals, vol. 11, pp. 75–92, 1921.

VEGETATION

The vegetation adapts itself closely to the climatic conditions, varying in character and quantity with exposure to sun and wind and with the distribution of moisture and temperature. The moister bottoms are covered with reeds, rushes, and wild grasses, which make an inferior hay. The lower mountain slopes and foothills together with the drier bottoms are largely covered with sagebrush, interspersed with grasses and weeds that are utilized for grazing.

The eastern foothills of the Portneuf Mountains and the western slopes and rounded summits of much of the Chesterfield Range are practically devoid of trees, but willows are to be found along the streams. The eastern slopes of the Chesterfield Range support many groves of aspen (*Populus tremuloides*) and somewhat tangled growths of brush. The higher slopes at the headwaters of Graves and Sawmill Creeks, particularly the east slope of the rocky ridge that forms the crest of the range in Tps. 5 and 6 S., R. 39 E., support some timber, chiefly lodgepole pine (*Pinus contorta*), Douglas fir (*Pseudotsuga taxifolia*), Engelmann spruce (*Picea engelmanni*), and possibly other conifers. Some logging was in progress in this area in 1923; the logs were being hauled out northward and sawed for local use.

SETTLEMENTS AND INDUSTRIES

The town of Chesterfield (population 690 in 1920) is practically the only settlement in the quadrangle. Mail and stage connections are maintained between this town and Bancroft (population 374), on the Oregon Short Line Railroad, about 10 miles to the south. Ranches, many of them deserted in 1923, are scattered over Portneuf Valley and along the foothills. The mountain region is practically uninhabited, although there are some fenced areas in the hills. Farming and stock-raising are the principal industries. The phosphate beds, described in detail on pages 69 to 89, may form the basis of phosphate mining at a future time.

TRANSPORTATION FACILITIES

The Oregon Short Line Railroad, which enters the southwestern part of the quadrangle, supplies the principal outlet for the country. A State highway follows the line of the railroad. Many roads, most of them passable by automobiles, traverse Portneuf Valley.

The Chesterfield Range forms a barrier not crossed by any good road between Tenmile Pass, at the southeast, and the pass near the line between Bingham and Caribou Counties, 1½ miles north of the quadrangle. Similarly, the Portneuf Mountains on the west are crossed by no road between the canyon of Portneuf River, at the south, and the road between Ross Fork and the Blackfoot Dam, near the Bannock-Bingham County line, at the north, which is part of the old Lander Trail from Wyoming to Snake River and the Pacific. There are roads that lead into or across the Chesterfield Range, but the through roads may not safely be traveled by automobiles and are hardly passable for wagons.

GEOLOGY

STRATIGRAPHY

THE STRATIGRAPHIC COLUMN

A detailed account of the stratigraphy of the general region of which the Portneuf quadrangle forms a part has been given in the larger report already cited, so that only brief descriptions of the formations represented are needed here. The stratigraphic column of the Portneuf quadrangle is fairly complete as high as the Jurassic. No Cretaceous sedimentary rocks are known, but a fault breccia recognized at several places is assigned to the mountain-building epoch that closed the Cretaceous period. No early Tertiary beds have been found, but the Salt Lake formation (Pliocene?) covers large areas. Quaternary beds of three sorts have been differentiated.

Because of the detailed studies made in neighboring areas and already published, few sections were measured in this quadrangle, but a detailed section was measured across one of the ridges of the Chesterfield Range on the north side of Monroe Canyon, in T. 7 S., R. 40 E., where excellent exposures of beds ranging in age from Silurian to Mississippian are to be seen. The following table summarizes the stratigraphy that is represented in the quadrangle. The distribution of the several formations is shown on Plate 1.

Stratigraphy of the Portneuf quadrangle

	Thickness (feet)
Quaternary:	
Recent: Alluvium.	
Pleistocene:	
Hill wash and older alluvium.	
Travertine.	
Unconformity.	
Tertiary:	
Pliocene (?): Salt Lake formation (chiefly conglomerate)	0–750+
Unconformity.	
Tertiary or Cretaceous: Fault breccia (chert fragments).	
Unconformity.	
Triassic (?): Higham grit	200±

	Thickness (feet)
Triassic:	
Lower Triassic:	
Timothy sandstone	800+
Unconformity.	
Thaynes group:	
Portneuf limestone	2, 600±
Fort Hall formation (sandstone, shale, and limestone)	800–1, 000
Ross Fork limestone	1, 800–2, 600
Woodside shale	2, 000±
Unconformity.	
Carboniferous:	
Permian: Phosphoria formation (chert and phosphatic shale and sandstone)	680±
Unconformity.	
Pennsylvanian: Wells formation (sandstone and limestone)	2, 100–3, 000
Unconformity.	
Mississippian:	
Brazer limestone	2, 088+
Unconformity.	
Madison limestone	612
Unconformity.	
Devonian:	
Upper Devonian: Threeforks limestone	180
Middle Devonian: Jefferson limestone	935
Unconformity.	
Silurian: Laketown dolomite	485+
Ordovician:	
Upper Ordovician: Fish Haven dolomite	700
Unconformity.	
Lower Ordovician:	
Swan Peak quartzite	700
Garden City limestone	1, 130
Unconformity.	
Cambrian:	
Upper Cambrian: St. Charles limestone	1, 300
Middle Cambrian:	
Nounan limestone	300±
Bloomington formation (limestone and shale)	400±
Blacksmith limestone	350±
Ute limestone	400±
Langston limestone	450±
Middle and Lower Cambrian: Brigham quartzite	1, 000–1, 600

CAMBRIAN SYSTEM

General features.—The oldest rocks recognized in the quadrangle are of Cambrian age and consist of quartzite, limestone, shale, and sandstone. In general, they represent Walcott's [15] sections in Blacksmith Fork, Utah, and 5 miles west of Liberty, Idaho, as modified by Richardson.[16] They occur at intervals for 8 miles along the southwest border of the quadrangle in the foothills of the Portneuf Range and are best exposed on the north side of King Creek in sec. 15, T. 7 S., R. 38 E., where practically the entire sequence is represented. The beds on the north side of the creek are here offset nearly half a mile eastward with respect to those on the south side by a fault that is followed by the course of the stream.

The boundaries indicated for the respective formations were drawn largely on lithologic data, which seemed fairly satisfactory, but fossils were collected at several localities that confirmed in a general way the conclusions shown in the mapping. Edwin Kirk, who kindly examined the collections, makes the following comment regarding them:

> It is a question whether the Cambrian formations of Walcott in Blacksmith Fork can be carried far laterally. The Cambrian varies greatly in lithology and the faunas are not sharply delimited. It is possible to make close correlations only when considerable collections of well-preserved fossils are available.

Brigham quartzite.—As the name implies, the Brigham quartzite is chiefly a massive quartzite, generally vitreous, and reddish, pinkish, purplish, or yellowish. Locally it contains pebbly bands, and the upper part consists largely of hard sandy micaceous shale. Its thickness in the general region ranges from 1,000 to 1,600 feet. In the Portneuf quadrangle the Brigham quartzite is exposed only in small areas north and south of Topons Creek, though it lies close to the western boundary much of the way southward from these areas. The stratigraphic section rises eastward here, so that the uppermost beds of the formation lie nearest to the quadrangle.

Langston limestone.—Beds assigned to the Langston limestone occur on the south side of Topons Canyon, where with beds of the Ute limestone they are included in a partly exposed syncline. They also occur in the King Creek section just west of the quadrangle boundary. The rock is a somewhat magnesian limestone with fine to medium granular crystalline texture and with glittering steel-gray color on fresh fracture. It weathers brown to gray. No fossils were observed in it in the Portneuf quadrangle, but it is moderately fossiliferous at its type locality in Blacksmith Fork, Utah. Its thickness in the King Creek section is about 450 feet.

Ute limestone.—In the Liberty section of the Ute limestone the lowermost beds, which are highly fossiliferous paper shales, are des-

[15] Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 53, pp. 5–9, 190–200, 1908; Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 148–153, 1912.

[16] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 406–416, 1913.

ignated the Spence shale member. In the general region of southeastern Idaho it has not been practicable to differentiate this member as a cartographic unit. In the King Creek section of the Portneuf quadrangle there is a topographic depression where the shale might be, but the shale itself was not recognized. The formation, however, here consists of bluish gray limestone with interbedded greenish-gray papery shales that are more noticeable in the talus slopes than in the ledges. A few fossils were collected from the limestone, including *Zacanthoides idahoensis* Walcott and *Bathyuriscus* sp., said by Edwin Kirk to be characteristic of the Ute. The thickness of the formation at King Creek is about 400 feet.

Blacksmith limestone.—The beds that constitute the Blacksmith limestone are similar to the upper beds of the Ute, but the bedding is more massive and the boundary between the two formations is usually marked by low cliffs. In the King Creek section no definite boundary was obtained and no satisfactory fossils were collected. The lower boundary was drawn at the point where the interbedding of shales with limestones ceases and the limestone beds become more massive. There are no noteworthy cliffs, but well-defined ledges occur. Near the top the beds are coarsely oolitic. The upper boundary was drawn at a topographic depression which it was thought might mark the position of the Hodges shale member of the Bloomington formation. The thickness of the Blacksmith limestone as thus mapped is about 350 feet.

Bloomington formation.—The presence of the Hodges shale member at the base of the Bloomington formation was suggested by shaly float on the east side of the topographic depression used as the upper boundary of the Blacksmith limestone. The beds on the east consist in part of coarsely oolitic gray limestone and in part of rock that is not oolitic. The top of the formation was mapped at a second topographic depression that was thought to correspond with the shaly rocks that elsewhere constitute the upper beds of the formation. Although the Bloomington formation at its type locality is abundantly fossiliferous, no satisfactory collection was obtained here. The thickness of the formation as mapped is about 400 feet.

Nounan limestone.—The Nounan limestone ordinarily consists of massively bedded, whitish or light gray, somewhat coarsely crystalline dolomitic limestone that sparkles on freshly fractured surfaces. It occurs in beds about 18 inches thick and alternating with these are dark gray beds of similar character and thickness with branching calcitic forms that are probably organic replacements. In the King Creek section beds of these types occur together with some oolitic beds. The thickness of the formation as mapped is about 300 feet.

St. Charles limestone.—In the Cambrian section north of King Creek only the Worm Creek quartzite member of the St. Charles formation is exposed. The quartzite forms the eastern tip of the hill, which ends abruptly. From conditions south of the canyon it is inferred that the limestone beds that normally make up the greater part of the formation have been faulted out or down so that they are now concealed by hill wash. Practically the full thickness of the quartzite member is preserved, however.

South of the King Creek Canyon, in the SE. ¼ SW. ¼ sec. 22 and the NE. ¼ NW. ¼ sec. 27, T. 7 S., R. 38 E., what is probably a very nearly complete section of the formation is exposed. Here the quartzite member is about 300 feet thick and the limestone member 1,000 feet thick. Northward from this locality a fault cuts obliquely across the formation, apparently shutting it out entirely at the south wall of the King Creek Canyon and introducing on the east the Garden City limestone (Ordovician).

The quartzite that forms a prominent knoll in the SE. ¼ SW. ¼ sec. 22 is pinkish or whitish and less vitreous than either the Brigham quartzite or the Swan Peak quartzite. The quartzite member is composed of successive beds a few inches thick and weathers into rough angular blocks. The limestone, which is in beds half an inch to 3 inches thick, is gray with yellowish spots and cherty, weathering with a rough cherty surface, and is decorated at the locality named with orange-colored lichens.

Recent work by Ulrich, Walcott,[17] and Resser, mostly unpublished, shows that the St. Charles limestone includes beds now believed to be of "Ozarkian" age.

Undifferentiated Cambrian.—In secs. 3, 10, 11, 14, and 15, T. 7 S., R. 38 E., ledges of limestone with Cambrian lithology are exposed. Determinable fossils are apparently few; the fragmentary remains that were collected proved to be of no value. Float pieces of quartzite, probably representing the Brigham quartzite, were found in the NW. ¼ SE. ¼ sec. 10 with limestone fragments both to the northwest and the southeast. If this material represents an actual occurrence of the Brigham, the pieces of quartzite would mark the location of a minor anticlinal fold in the Cambrian succession or, perhaps, a fault. More probably these pieces as well as the blocks of Swan Peak quartzite in the NE. ¼ NE. ¼ sec. 15 are to be considered as débris weathered out of the Salt Lake formation. They have been so mapped.

The undifferentiated Cambrian is distinguished on the map by a different pattern from those of the designated formations.

[17] Walcott, C. D., Cambrian geology and paleontology, Cambrian and Ozarkian trilobites: Smithsonian Misc. Coll., vol. 75, p. 127, 1925.

In the SW. ¼ SW. ¼ and the SE. ¼ sec. 18, T. 5 S., R. 39 E., masses of Cambrian limestone large enough to be considered ledges appear in the midst of the Salt Lake formation. If they are in fact ledges, their position athwart the strike of Carboniferous rocks indicates the presence of a concealed fault. The Salt Lake formation, however, contains at some localities boulders of Ordovician quartzite and other rocks 4 or 5 feet in diameter. There is therefore the possibility that these supposed ledges may be large detached masses included in the Salt Lake formation.

ORDOVICIAN SYSTEM

Ordovician rocks are exposed only in the southwestern part of the quadrangle, where all three of the subdivisions distinguished for the general region by Richardson [18] have been identified. They form part of the King Creek section on the south side of the canyon and comprise a number of rocky promontories and isolated knobs. Distinctions here too have been made largely on lithologic grounds, for there has been little difficulty in recognizing the formations. Fossils are poorly preserved and the collections were highly unsatisfactory.

Garden City limestone.—A characteristic feature of the Garden City limestone is the presence, at intervals throughout the formation, of beds of conglomerate or breccia, consisting of elongated fragments of gray or yellowish-gray limestone of various sizes, the largest 2 or 3 inches long, embedded in a matrix of similar composition. There are also streaks of yellowish-brown chert approximately parallel to the bedding and beds of purer limestone, some of which are rather massive, a foot or more thick. Annelid borings were noted at one locality. The Garden City limestone carries a Beekmantown fauna, but no satisfactory collections were obtained in the Portneuf quadrangle.

In the King Creek section limestone beds in the NE. ¼ sec. 22, T. 7 S., R. 38 E., are assigned to the Garden City. They are not well exposed, but from their relations to well-recognized Swan Peak beds on the east and from their lithology near the fault that cuts out the Worm Creek quartzite member of the St. Charles there seems little doubt of the correctness of the assignment. The Garden City limestone appears in the SW. ¼ sec. 23, NW. ¼ sec. 26, SE. ¼ sec. 27, and NE. ¼ sec. 34. The largest exposure is in the E. ½ sec. 3, T. 8 S., R. 38 E., and adjoining territory on the north, where the exposed thickness is about 1,130 feet.

[18] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 406–416, 1913.

Swan Peak quartzite.—The whitish, vitreous, blocky appearance of the Swan Peak quartzite serves in most places to distinguish it from the Brigham and Worm Creek quartzites below and from quartzitic sandstones of Pennsylvanian age above. Locally the Swan Peak beds are pinkish or reddish and softer, and there the distinction is more difficult. The formation makes rough, blocky, and ledgy hills that are conspicuous topographic features. (See pl. 4, *B*.) It underlies the rocky knoll in secs. 13 and 14, T. 7 S., R. 38 E., and forms the east end of the ridge south of King Creek. It constitutes the eastern part of the knoll in the SW. 1/4 sec. 23 and the southeast tip of the hill in sec. 26. The rocky hills and ridges in secs. 35 and 36 and farther south are composed mainly of Swan Peak quartzite, and so are some small rocky knobs in secs. 5 and 8, T. 8 S., R. 39 E., near the south boundary of the quadrangle. The total thickness is not exposed, but the formation is probably not less than 700 feet thick. The fauna of the Swan Peak quartzite has been tentatively referred to the Chazy by Ulrich and Kirk.

Fish Haven dolomite.—Beds assigned to the Fish Haven dolomite are exposed at only a few scattered localities in the southwestern part of the quadrangle. The largest area is the southeastward-projecting knoll in the NW. 1/4 sec. 14, T. 7 S., R. 38 E. Here the beds are massive bluish-gray limestone striking N. 42° W. and dipping 45° SW. The lithology suggests the Fish Haven, and the strike is at sharp variance with that of beds believed to be of Middle Cambrian age that make up the main hill from which the knoll projects. It is therefore believed that the supposed Fish Haven beds are faulted against the Cambrian beds. The thickness of the Fish Haven at this locality is at least 700 feet. At other localities, which are in secs. 5 and 8, T. 8 S., R. 39 E., the relations of the rock to the Swan Peak quartzite are such as to leave little doubt of the identity of the formation. The exposures at these localities are so small that no idea of the thickness of the formation here can be obtained.

The Fish Haven dolomite is normally a dark-gray to blue-black, locally cherty dolomite about 500 feet thick and carries a fauna of Richmond age.

SILURIAN SYSTEM

The Silurian system in southeastern Idaho is represented by a single formation that in the regions thus far studied is confined to small, disconnected areas. It is better developed in the Randolph quadrangle, Utah, where it was originally studied by Richardson.[19]

[19] Richardson, G. B., op. cit.

In the Portneuf quadrangle the only exposures are in a small area on the southwest flank of the Chesterfield Range.

Laketown dolomite.—In secs. 29 and 32, T. 7 S., R. 40 E., the beds exposed near the base of the slope and just above the hill wash consist of light-gray to white porous crystalline rock that weathers with a rough and cavernous surface and closely resembles the Laketown dolomite in general lithology. They occupy a position appropriate for this formation with reference to overlying formations and are therefore confidently assigned to the Laketown. The beds comprise Nos. 1 to 3 of the section measured north of Monroe Canyon (p. 23), with a thickness of 485 feet, but the base is not exposed. A single lot of poorly preserved fossils contained *Favosites favosus* (Goldfuss) and *Pentamerus* cf. *P. oblongus* Sowerby, as identified by Edwin Kirk, who assigns the formation to the Niagaran epoch.

DEVONIAN SYSTEM

In this general region the Devonian system is represented by two formations, both of which are exposed in the Portneuf quadrangle along the southwest flank of the Chesterfield Range north and south of Monroe Canyon, where they occupy parts of the lower slopes and foothills. These are the Jefferson limestone and the Threeforks limestone. Devonian rocks also continue southeastward into the Soda Springs Hills beyond the limits of the quadrangle.

Jefferson limestone.—The contact zone between the Laketown and the Jefferson is readily distinguished by the marked change in lithology, the Jefferson weathering to a chocolate-brown and having a dark-gray color on fresh fracture. The rock is dolomitic and much broken and is seamed here and there with calcite. There are, however, some light-colored beds that in general appearance are not unlike the Laketown or some of the beds of the Madison. Poorly preserved fossils were found, among which Edwin Kirk identified *Pachyphyllum woodmani* White, *Atrypa reticularis* (Linnaeus), *Stromatopora* sp., *Diphyllum* sp., and *Cladopora?* sp.

Beds here assigned to the Jefferson include Nos. 4 to 13 of the section measured north of Monroe Canyon (p. 23) and have a thickness of 935 feet.

Threeforks limestone.—The contact zone between the Jefferson and the Threeforks is also fairly well distinguished, the Jefferson making good ledges and furnishing large blocky float pieces, whereas the Threeforks is thinner bedded, makes no ledges, and supplies a light, somewhat varicolored float of sandy limestone or limy sandstone in flat pieces generally not more than 3 or 4 inches across.

In the Monroe Canyon section (p. 23) the beds here assigned to the Threeforks include Nos. 14 to 16 and have a thickness of 180 feet. The contact zone of the Threeforks with the overlying Madison and probably some of the Madison beds as well are covered with débris of the Salt Lake formation, which must once have covered most if not all of the rocks now exposed in the section.

Southeast of Monroe Canyon the Threeforks limestone diminishes rapidly in thickness, and in the NE. ¼ sec. 4, T. 8 S., R. 40 E., it is represented by only a few feet of beds. Southwest of Tenmile Pass it seems to be entirely absent, and the relations of the Madison to the Jefferson indicate unconformity rather than faulting. It is therefore believed that the Threeforks limestone may once have been much thicker but that it had been largely eroded away at the time of deposition of the Madison.

CARBONIFEROUS SYSTEM

A full sequence of Carboniferous formations is present in the Portneuf quadrangle, but they are not all exposed at any one locality. The Chesterfield Range is apparently composed largely of Carboniferous rocks, though these are much concealed by Tertiary beds. Carboniferous beds also underlie considerable tracts in the Blackfoot Mountains, especially in the Paradise Valley quadrangle, on the north. They consist chiefly of limestone with some sandstones and with subordinate cherty and shaly members, including economically important beds of phosphate rock. The aggregate exposed thickness of the system is nearly 6,200 feet.

MISSISSIPPIAN SERIES

The Mississippian series includes the Madison limestone below and the Brazer limestone above. Both formations are characterized by rather pure limestone, but both include rock of other types, and there are also faunal differences. The Mississippian series is well represented in the section measured north of Monroe Canyon in T. 7 S., R. 40 E. This section also contains Devonian and Silurian beds, but it is inserted here because of the great preponderance in it of Mississippian beds. The section was measured in a direction at right angles to the strike with a 5-foot rule to which was attached a clinometer. Offsets were made here and there along the strike in order to utilize more favorable ground for travel or to visit more favorable exposures.

Section of Paleozoic beds north of Monroe Canyon in secs. 32 and 28, T. 7 S., R. 40 E., Idaho

Field No.		Thickness
	Concealed; top of section.	*Feet*
36	Limestone float, bluish gray, with low-lying ledges	5+
35	Limestone, massive, dense, medium gray, fairly free from chert. Corals and brachiopods of Brazer age	425
34	Limestone, dark bluish gray, with cherty nodules; weathers sandy; strike N. 35° W., dip 45° E	80
33	Limestone, dark bluish gray, cherty, streaked with calcite, coarser textured and lighter gray in the upper part; fossiliferous; strike N. 35° W., dip 68° E	100
32	Limestone, massive, gray, forming crest of ridge, cherty nodules, fossiliferous	230
31	Limestone float, gray, similar to beds below	160
30	Limestone, massive, bluish gray, beds as much as 4 feet thick, chert nodules and bands about 20 feet above base	60
29	Limestone, massive, light gray, relatively pure, fossiliferous	100
28	Limestone, very massive, sandy streaks, cross-bedding	75
27	Limestone, light gray, massive, but with some thin sandy beds, fossiliferous; 15 feet above base many shell fragments	120
26	Sandy and limy beds, yellowish, thin bedded	58
25	Limestone, light gray, massive, with chert streaks and nodules in bands at 4 to 6 inch intervals, fossiliferous	40
24	Limestone, dove-colored to drab, massive, beds 1 to 10 feet thick; strike N. 35° W., dip 40° E	42
23	Limestone, light gray, sandy; weathers into angular blocks; strike N. 35° W., dip 25° E	108
22	Sandstone, weathering yellowish and reddish, thin bedded; no ledges exposed; float intermingled with chert fragments; more calcareous toward top	405
21	Limestone, platy, sandy and cherty, weathering pink to purplish, indistinct fossils; freshly broken rock has odor of petroleum; no ledges	80
20	Limestone, light gray, thin bedded; no ledges; weathers drab to pink or reddish	195
19	Limestone, gray, massive, finer and more sandy toward the top; float becoming thin-bedded and weathering drab to pink; Madison fossils	390
18	Limestone, gray, more or less concealed by Salt Lake formation; strike N. 35°-40° W., dip 30° E	25
17	Limestone, massive bed, projecting through cover of Salt Lake formation; base of Madison (?)	2
16	Débris of Salt Lake formation covering older beds	10
15	Calcareous beds, reddish and yellowish, rather fine float, pieces not usually larger than 3 or 4 inches; no ledges, much more reddish yellow near top	140
14	Limestone, gray, weathering pinkish or purplish in pieces 1 foot or more in diameter; no ledges	30
13	Limestone, gray ledges, individual beds as much as 1 foot thick; lower beds are limestone breccia; fine banding on weathered surface	70
12	Limestone, light brownish gray, weathering to thin slabs; no ledges; finer float red, pink, drab, or yellow	295
11	Limestone, grayish brown, beds 1 foot or more thick, fine banded; strike N. 30° W., dip 30° E	110
10	Limestone, brownish, highly fractured, a few chert nodules as much as 6 inches in diameter, beds as much as 1½ feet thick, finely banded on weathered surface	30
9	Limestone, massive, brownish gray, much fractured; contains small linear and branching organisms and a few corals of Jefferson age	80
8	Limestone, light grayish brown, massively but indistinctly bedded and highly fractured, black cherty patches	55
7	Limestone, like beds below but weathering smooth and fractured; fewer ledges	20
6	Limestone, massive; some beds as much as 3½ feet thick	77
5	Limestone, grayish brown, massive; well-marked ledges	48
4	Limestone, dark brownish gray, much fractured and seamed with calcite, beds 1 foot or more thick, Jefferson lithology; strike N. 35° W., dip 20° E	150
3	Dolomite, gray, crystalline; no good ledges; Laketown lithology	120
2	Dolomite, massive, like No. 1; contains many poorly preserved fossils, some silicified, of Laketown age	250
1	Dolomite, gray, finely crystalline, massive, beds as much as 2½ feet thick; strike N. 40° W., dip 21° E	115
	Covered area, base of slope and bottom of measured section.	
		4,300

Madison limestone.—In the Portneuf quadrangle the Madison limestone is exposed only on the southwest flank of the Chesterfield Range and Soda Springs Hills, southeastward from Little Flat Canyon, in sec. 19, T. 7 S., R. 40 E. The northernmost exposure is in a gully carved in the face of the travertine cliff at the mouth of the canyon, where a sharp and broken fold of the Madison beds, formerly concealed by travertine, has been uncovered. (See pl. 4, *C*.) The Madison limestone as here exposed consists mainly of thin-bedded dark bluish-gray limestone that weathers brown or gray, but at the base there are beds of more massive lighter-colored limestone, some of which is crinoidal and coarsely crystalline. Below lie the varicolored beds of the Threeforks, in which the dip and strike are not well shown.

The strike of the Madison is about N. 45° W. The dip in the southern part of the exposure is 30°–35° NE., locally as low as 12°; in the northern part it is considerably steeper, about 59° on the point south of Little Flat Canyon. This difference in dip is in accord with the facts stated in the discussion of the Threeforks limestone, where the unconformable relation of the two formations was pointed out. Southeast of Tenmile Pass the basal beds of the Madison consist of a breccia, apparently of sedimentary origin, composed of a light-gray matrix of Madison lithology with fragments of chocolate-colored Jefferson or of varicolored Threeforks. The Madison here rests directly upon the Jefferson.

The top of the Madison as here mapped is composed of thin-bedded gray limestone that lies just beneath a dark cherty and somewhat phosphatic shale, thought to represent the phosphatic member of the Brazer limestone, which is recognized at several places farther south. This shale occurs pretty uniformly along the hillside in T. 7 S., R. 40 E., and in general the two formations seem fairly conformable. On the spur south of Little Flat Canyon, however, the Madison dips much more steeply than the Brazer, so that it is probable that here as elsewhere farther south the two formations are really unconformable.

In the Monroe Canyon section the beds here assigned to the Madison include Nos. 17 to 20 and have a thickness of 612 feet. The Madison limestone is not so well exposed on the slope northeast of Monroe Canyon as it is on the slopes to the southeast, where the relation of the upper beds to the overlying cherty beds of the Brazer is better shown.

Fossils were collected at several horizons in the Madison from which G. H. Girty has identified the following forms:

Syringopora surcularia.
Triplophyllum excavatum.
Lithostrotionella n. sp.
Crania sp.
Leptaena analoga.
Schuchertella chemungensis.
Chonetes loganensis.
Productus sp.
Avonia sp.
Pustula aff. P. concentrica.
Camarotoechia metallica.
Dielasma sp.
Spirifer centronatus.
Reticularia cooperensis.
Nucula sp.
Parallelodon sp.
Schizodus sp.
Cypricardinia aff. C. scitula.

Bellerophon mansfieldianus.
Bucanopsis sp.
Pleurotomaria, several sp.
Platyceras sp.
Euomphalus utahensis.
Euomphalus luxus?
Straparollus ophirensis.
Naticopsis sp.
Loxonema sp.
Orthoceras sp.
Griffithides sp.
Ostracoda undet.

Brazer limestone.—Considerable areas in the Chesterfield Range are underlain by the Brazer limestone. It is exposed on both sides of Tenmile Pass at the southeast and in company with older formations it extends thence northwestward, forming a high, rocky ridge between that pass and Little Flat Canyon. It is also exposed in small areas at the heads of Tenmile Creek (sec. 11, T. 7 S., R. 40 E.) and Eighteenmile Creek (sec. 33, T. 6 S., R. 40 E.). Farther northwest a larger area extends as far as the main canyon of Thompson Creek, in sec. 20, T. 6 S., R. 40 E. The Brazer emerges from a Tertiary cover in the northwest corner of sec. 18, T. 6 S., R. 40 E., and extends as far northwestward as the southeast corner of sec. 19, T. 5 S., R. 39 E., where it again passes under cover. Beds assigned to the Brazer also occupy part of the slope in the W. ½ sec. 18, T. 6 S., R. 39 E.

The Brazer limestone is characterized chiefly by massive, generally light-gray limestone that is prominent as a ridge and cliff maker (see pls. 3, *A*, and 5, *A*) and that in certain beds is highly fossiliferous.

According to G. H. Girty corals play a much more prominent part in the Brazer fauna than in most faunas of Carboniferous age in North America. Especially conspicuous and characteristic are cup or horn corals distinguished by their large size and numerous slender septa. Some of these have been identified as *Cyathophyllum? multilamella*, and large specimens reach a length of 8 inches and a diameter of 2½ inches. In some beds these are very plentiful associated with slender tubular colonies (*Syringopora*) and other colonies of the *Lithostrotion* type, some forming hemispherical masses and others having a bushy habit. The massive forms all appear to belong to the genus *Lithostrotionella*, the others to *Lithostrotion*. Collection from a number of localities yielded the following forms:

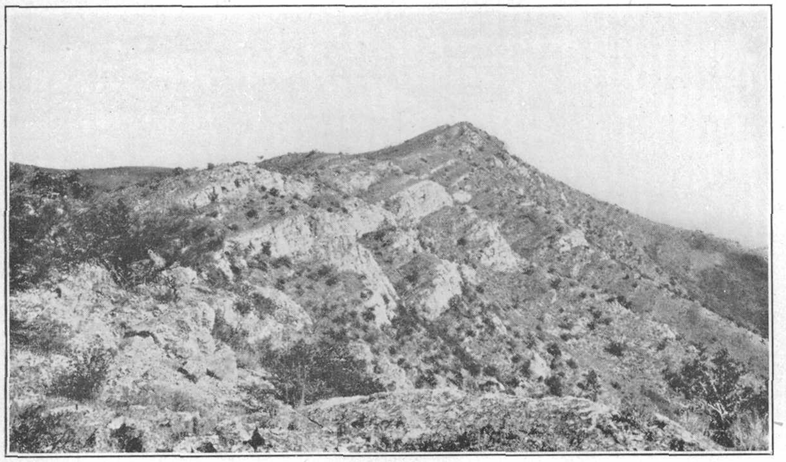
Syringopora aff. S. surcularia.
Lithostrotion sp.
Lithostrotionella n. sp.
Cyathophyllum? multilamella.
Anisotrypa sp.
Batostomella sp.
Fenestella, several sp.
Streblotrypa sp.
Productus brazerianus.
Productus aff. P. inflatus.
Avonia? n. sp.
Pustula n. sp.
Dielasma n. sp.
Spirifer brazerianus.
Spirifer aff. S. bifurcatus.
Cliothyridina sublamellosa.

In the Monroe Canyon section beds here assigned to the Brazer include Nos. 21 to 36 and have a total thickness of 2,088 feet without including the top of the formation. Exposures in Little Flat Canyon, however, indicate that the contact between the Wells and Brazer is not far back of the southwest edge of the Tertiary cover.

The cherty and phosphatic beds at the base of the Brazer are represented by the 80 feet of beds in No. 21 of the measured section. Above these comes 405 feet of thin-bedded sandstone, which is better exposed on the slopes southeast of the canyon, where there are well-marked ledges and where the change to the overlying massive limestone is rather abrupt. Although sandy beds have been noted elsewhere in the Brazer, sandstone of this type is unusual in this formation. Possibly its absence in other localities may be due to the same unconformable relations that render the occurrence of the underlying cherty and phosphatic beds somewhat sporadic.

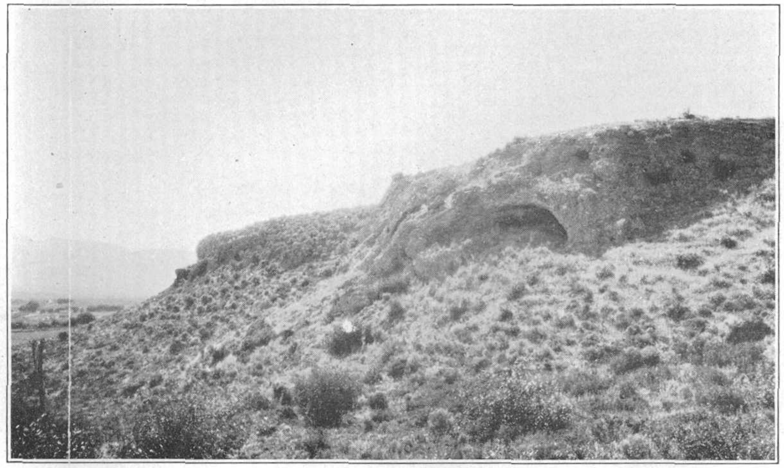
PENNSYLVANIAN SERIES

Wells formation.—The rocks of the Pennsylvanian series all belong to the Wells formation, which, like the Brazer limestone, is a prominent ridge-maker and is well exposed in several parts of the Chesterfield Range. The actual distribution of the Wells formation in the Portneuf quadrangle is undoubtedly much wider than is shown by the exposed areas. A blanket of Tertiary sediments now conceals extensive structural features in which the Wells must be abundantly represented. Small areas assigned to the Wells occur in sec. 26, T. 7 S., R. 40 E., and in secs. 16 and 17 of the same township, where the Tertiary cover is cut through by Little Flat Canyon, and a single ledge is exposed in the SE. ¼ NE. ¼ sec. 7, on the north side of Eighteenmile Canyon. A larger area occurs in secs. 25 and 26 and adjacent territory, T. 6 S., R. 39 E. A small ledge in the NW. ¼ SW. ¼ sec. 24 is probably to be assigned to the Wells, but if so its presence there indicates a fold or fault intervening between it and the larger area just mentioned. The favored interpretation, shown in structure section F–G, Plate 2, is consistent with the known structural features of the quadrangle. The Wells is exposed continuously in a relatively narrow belt that extends with curving trend first northward and then northwestward from the SE. ¼ SW. ¼ sec. 28, T. 6 S., R. 40 E., as far as the SE. ¼ sec. 20, T. 5 S., R. 39 E., where it passes again beneath Tertiary beds. This belt forms much of the crest of the main ridge and divide of the Chesterfield Range. The Wells is also exposed in small areas in secs. 5, 6, 15, and 17, T. 6 S., R. 39 E., and a larger area extends northwestward from sec. 18 of the same township to secs. 35 and 36,

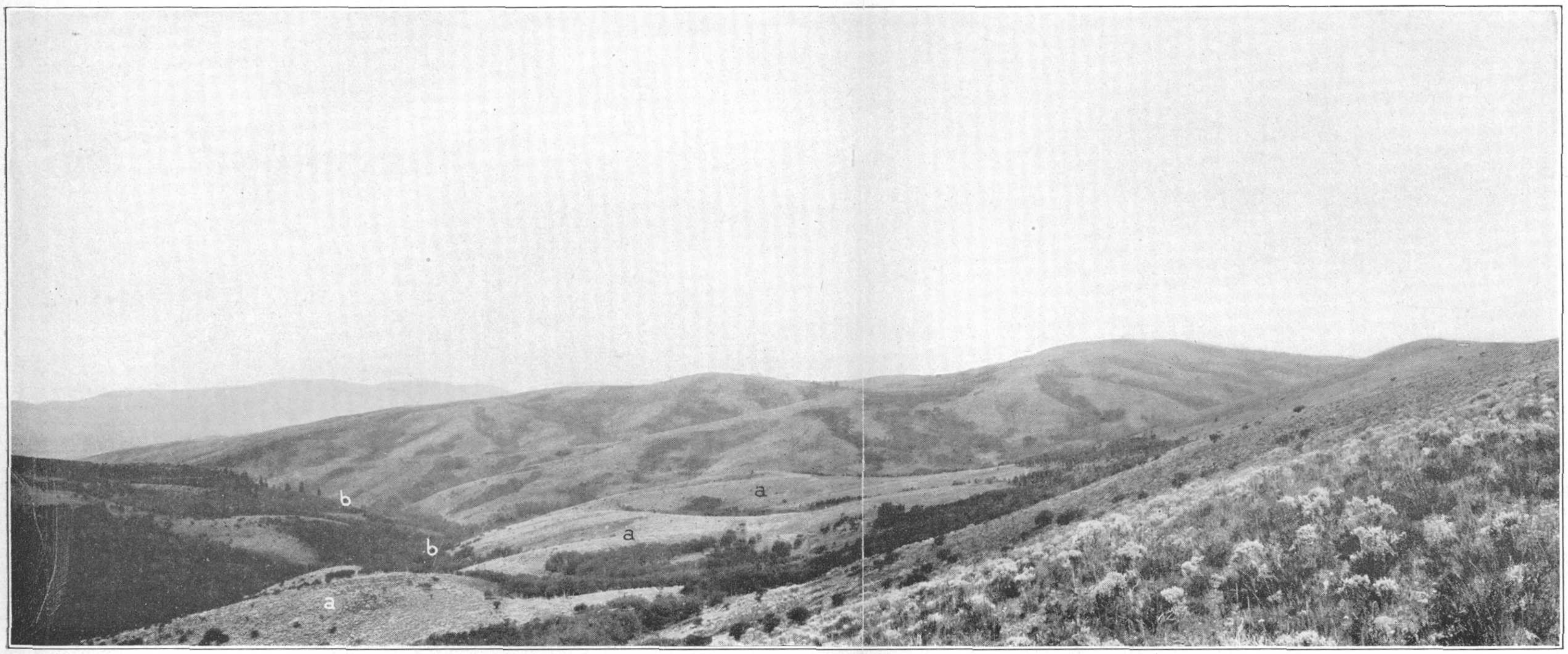


A. RIDGE OF BRAZER LIMESTONE NORTHWEST OF MONROE CANYON, T. 7 S., R. 40 E.

View southeastward from vicinity of Little Flat Canyon

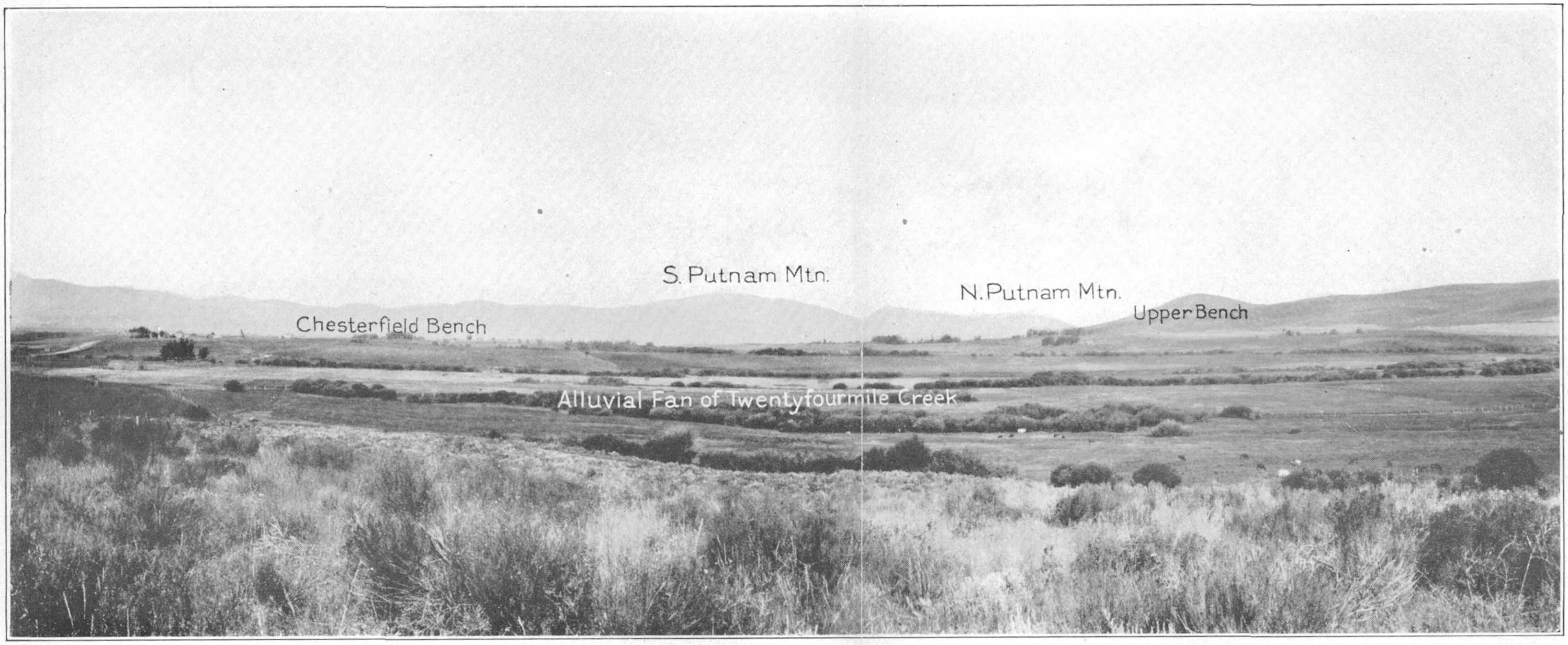


B. TRAVERTINE CLIFF WITH CAVE AT MOUTH OF EIGHTEENMILE CANYON, SEC. 12, T. 7 S., R. 39 E.



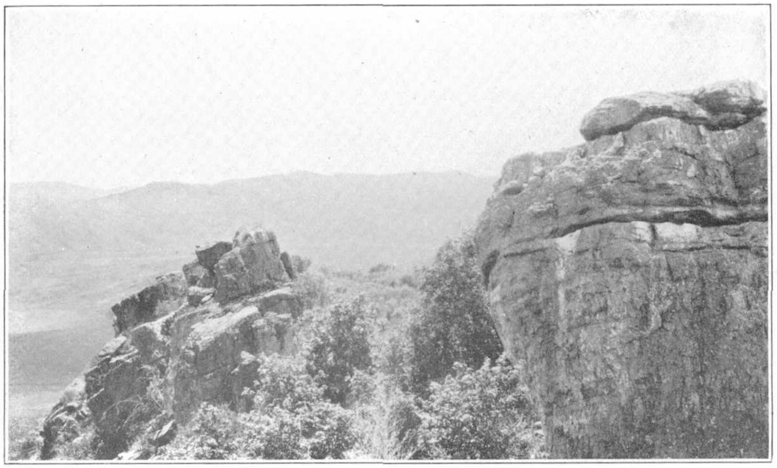
C. VIEW NEAR FORKS OF EIGHTEENMILE CREEK, T. 7 S., R. 40 E.

Shows former valley of Dry Fork age (a) now cut by valleys of the Blackfoot cycle (b)

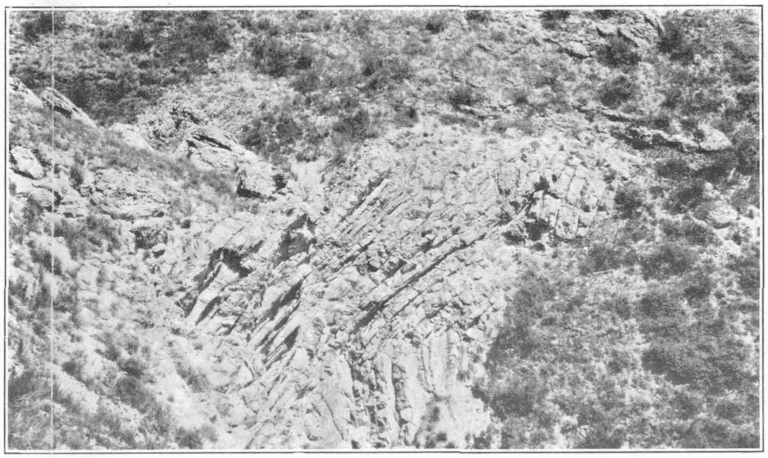


A. TERRACES AT MOUTH OF TWENTYFOURMILE CANYON, CHESTERFIELD

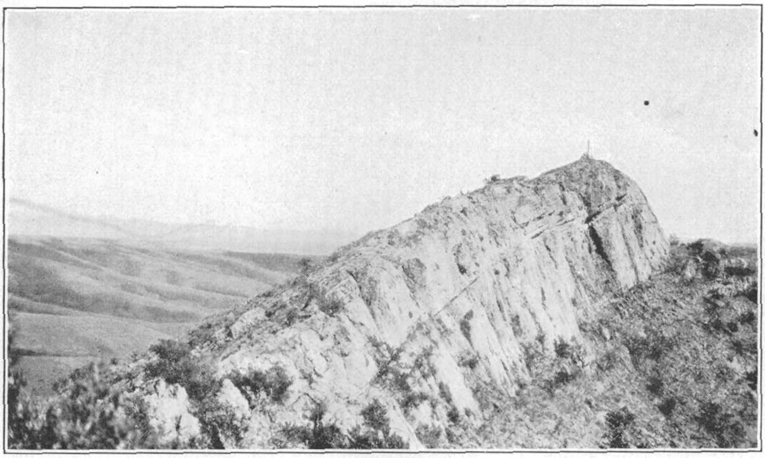
The hills at the right consist mostly of the Salt Lake formation. Note the smooth slopes



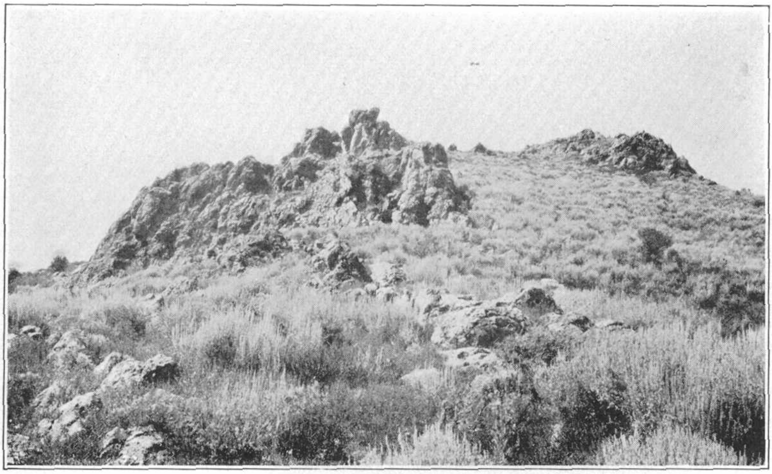
B. HILL OF SWAN PEAK QUARTZITE IN SEC. 35, T. 7 S., R. 38 E.



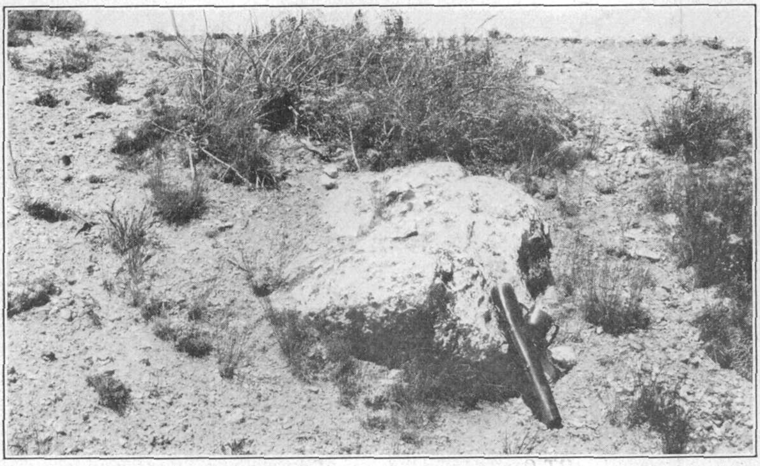
C. FOLD IN MADISON LIMESTONE UNCOVERED BY EROSION OF TRAVERTINE, SEC. 19, T. 7 S., R. 40 E.



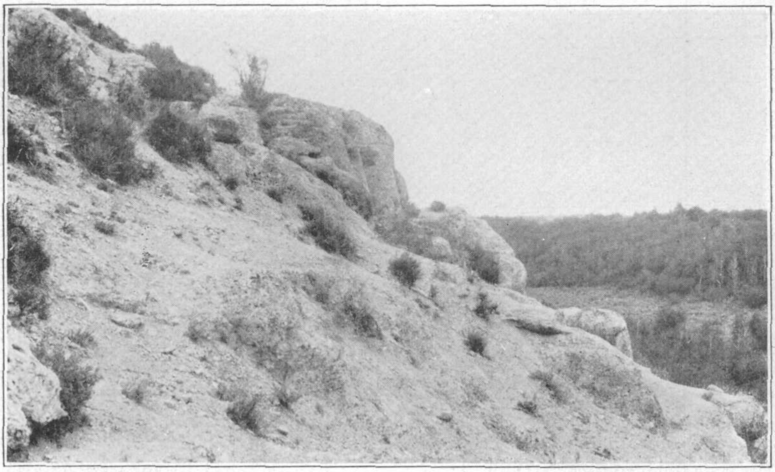
A. SUMMIT OF RIDGE IN SE. ¼ SEC. 20, T. 7 S , R. 40 E.



B. LEDGES OF REX CHERT IN SEC. 10, T. 6 S., R. 39 E.

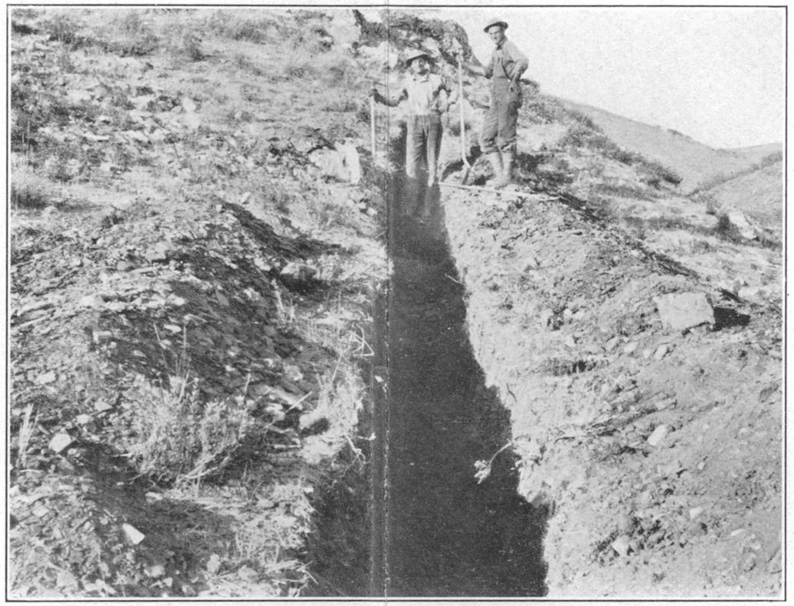


A. LEDGES OF SALT LAKE FORMATION, SEC. 2, T. 5 S., R. 38 E., PARADISE VALLEY QUADRANGLE

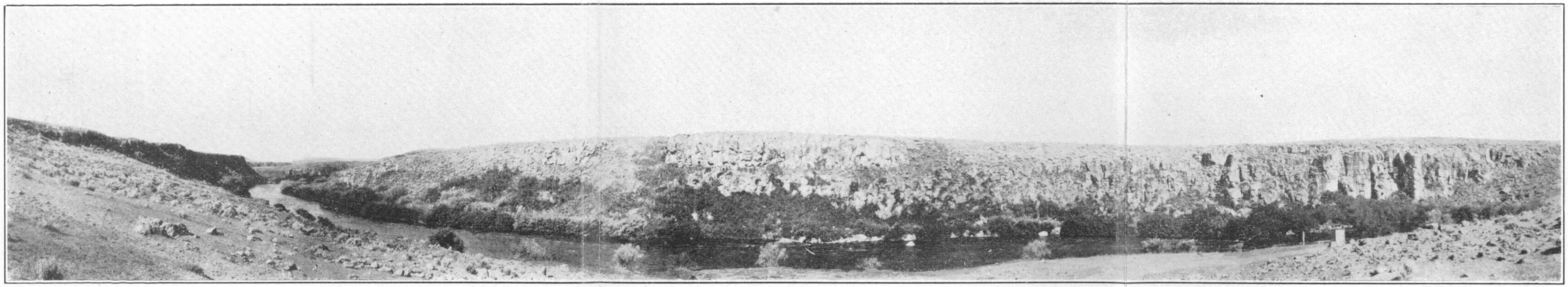


B. MASSIVE LEDGES OF SALT LAKE FORMATION BY ROAD IN NW. ¼ SEC. 6, T. 5 S., R. 39 E.

A. SPRING CONE OF TRAVERTINE IN SEC. 15, T. 5 S., R. 40 E.



B. PROSPECT MADE BY GEOLOGICAL SURVEY PARTY IN PHOSPHATIC SHALES IN SE. ¼ SEC. 34, T. 4 S., R. 40 E.



C. CANYON OF BLACKFOOT RIVER BELOW DAM IN SECS. 11 AND 12, T. 5 S., R. 40 E., CRANES FLAT QUADRANGLE

T. 5 S., R. 38 E. There is also an area in secs. 30 and 31, T. 5 S., R. 39 E, and a small interrupted strip in secs. 29, 30, and 19, T. 5 S., R. 40 E.

The threefold subdivision of the Wells noted in other parts of the region is observed in the Portneuf quadrangle. The lower beds of the Wells are massive limestones, generally more sandy and cherty than the massive beds in the upper part of the Brazer. The cherts are either characteristically ovoid, 4 inches or more long, and concentrically banded, or discrete irregular masses rather than bands or streaks, though some of these are present. The occurrence of branching Bryozoa and of the big brachiopod *Spirifer rockymontanus* (*S. opimus* Hall var. *occidentalis* Girty)[20] are also distinctive features of the lower Wells.

The middle sandstone member forms steep slopes strewn with débris but makes few or inconspicuous ledges except in the steeper-sided gullies. On the east slope of the main divide in the Chesterfield Range the vegetation is so dense that there are few exposures, and even the débris is largely concealed.

The upper siliceous limestone member forms prominent ledges or knobs along the hillsides, which are emphasized by the relative weakness of the overlying phosphatic shale beds.

A number of fossil collections were made from the Wells formation, which have been identified by G. H. Girty as follows:

Stenopora aff. S. carbonaria.	Spirifer opimus var. occidentalis.
Rhombopora lepidodendroides.	Spirifer cameratus.
Cystodictya sp.	Spiriferina spinosa?
Productus cora.	Composita subtilita.
Productus coloradoensis.	Cleiothyridina orbicularis.
Pustula nebraskensis.	Aviculipecten sp.
Marginifera splendens?	Phillipsia sp.

The thickness of the Wells as exposed in Tps. 5 and 6 S., R. 39 E., ranges from about 2,100 to 3,000 feet, as shown on Plate 1 and in structure sections A–B and C–D, Plate 2. There is little discordance in strike and dip between adjacent beds of the Wells and the underlying Brazer, but the boundary of the Wells transgresses certain beds of the Brazer, and parts of the Brazer represented in the Preuss and Webster Ranges, farther southeast, are absent here. It is therefore concluded that the Wells and Brazer are unconformable.

PERMIAN SERIES

Phosphoria formation.—The Permian strata constitute a single formation, the Phosphoria, which, though not of great thickness, maintains a nearly uniform character over wide areas. The rocks

[20] U. S. Geol. Survey Prof. Paper 152, pp. 433, 434, 1927.

are exposed in narrow bands along the flanks of the larger, more simple folds and in more complex crumplings in the smaller folds or along the borders of faulted areas. The Phosphoria formation is of great economic and scientific interest because it contains the extensive deposits of high-grade phosphate rock that constitute the chief mineral resource of the region. There are four principal bands of the Phosphoria formation within the Portneuf quadrangle, besides several minor occurrences. In the northeasternmost band, which includes parts of secs. 9, 15, and 16, T. 5 S., R. 40 E., only the upper cherty member of the formation is exposed. A second band, in which the phosphatic shales are intermittently exposed, extends northwestward from the NW. 1/4 sec. 33 in the same township. A third band, the longest within the quadrangle, extends 5 miles northwestward from the SW. 1/4 SE. 1/4 sec. 1, T. 6 S., R. 39 E. A number of exposures related to broken folds occupy an area that includes the junction of Tps. 5 and 6 S., Rs. 38 and 39 E., and extends southeastward. Isolated areas of chert in sec. 8, T. 6 S., R. 39 E., indicate that considerable areas now occupied by Tertiary beds are probably underlain by the Phosphoria. In secs. 24 and 25 of the same township the formation is exposed in a strip more than a mile long. In sec. 10 of the same township, where the East Fork of Twentyfourmile Creek cuts through the ridge, ledges of chert assigned to the Phosphoria are conspicuously exposed on the north side of the canyon. (See pl. 5, *B*.) Further reference to this exposure is made on page 53.

The lower portion or phosphatic shale member of the Phosphoria formation ordinarily consists of 75 to 180 feet of yellowish to brown phosphatic sandstone, dark-brown to black phosphatic shale, beds of brown or black fetid limestone, and one to three economically important beds of phosphate rock. The phosphate rock is characterized by gray, brown, or black color, fine to coarse oolitic texture, and a strong fetid odor when freshly broken. Weathered fragments or float pieces have a characteristic bluish-white bloom, many with white reticulate markings. The thickest and richest bed of phosphate rock is usually at or near the base and ranges in thickness from 4 to 7 feet or even more over large areas. The other beds of possible economic importance are thinner and occur near the top and middle of the shale interval. Details of phosphate occurrences are given in the discussion of individual townships.

The phosphate rock itself is practically nonfossiliferous, so far as observed, although a few discinoids and bone fragments have been found, and locally in the region there is a bed that contains many shell fragments close to the base. The beds that accompany the phosphate rock are, however, to a certain extent fossiliferous. The following fossils have been identified by G. H. Girty from localities within or near the Portneuf quadrangle:

Lingula carbonaria?
Lingulidiscina missouriensis.
Chonetes ostiolatus.
Productus geniculatus.
Productus eucharis.
Productus phosphaticus.
Pustula montpelierensis.
Pugnax weeksi.
Leda obesa.
Aviculipecten montpelierensis.
Omphalotrochus conoideus.
Omphalotrochus ferrieri.

The Rex chert member, which constitutes the upper division of the Phosporia formation, is generally conspicuous because its superior hardness enables it to stand out in strong cliffs, ledges, or prominent knolls. The phosphatic shale, on the other hand, is topographically weak and in many places eroded into gullies and depressions. In the Portneuf quadrangle, the limestone facies, which appears in the Rex chert member in other areas, was not found. The principal exposures show the flinty shale that is characteristic of the member in much of the general region, but locally, as in sec. 10, T. 6 S., R. 39 E., the chert forms massive ledges.

In the limestone facies of the Rex in other parts of the general region fossils are abundant. Characteristic fossils of this horizon, according to G. H. Girty, include the following:

Productus multistriatus.
Pustula subhorridus.
Spirifer pseudocameratus.
Spiriferina pulchra.
Composita subtilita var.

At some places where massive chert beds are exposed sponge spicules and casts of crinoid stems have been found, but in the Portneuf quadrangle no fossils were seen in the Rex.

The thickness of the Rex as exposed in sec. 29, T. 5 S., R. 40 E., is about 500 feet.

TRIASSIC SYSTEM

Beds assigned to the Triassic system are exposed at many places in the northern third of the quadrangle, especially in the northeastern part. In the general region of southeastern Idaho,[21] not including the Portneuf quadrangle, three divisions with an aggregate maximum thickness of 5,350 feet, have been distinguished and assigned to the Lower Triassic series—namely, the Woodside shale, Thaynes group, and Timothy sandstone. In addition three other formations of uncertain age with a combined thickness of 550 feet are provisionally assigned to the Triassic. These are the Higham grit, Deadman limestone, and Wood shale. All but the last two of these subdivisions are represented in the Portneuf quadrangle.

The relations of the Triassic to the Permian are not fully understood. The field relations suggest conformity between the two, for the boundary between the Woodside and Phosphoria is generally

[21] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 85–95, 1927.

very regular and the attitudes of the two formations correspond closely. There is no conglomerate at the base of the Woodside and no evidence of erosion in the Phosphoria preceding the deposition of the Woodside, unless the somewhat variable thickness of the Phosphoria is so considered. On the other hand, there are striking faunal and lithologic differences between the two formations, and it is believed that a stratigraphic break (unconformity) of some magnitude intervenes. The nomenclature of the Triassic in southeastern Idaho and the relations of the Triassic to the Permian are more fully discussed in the larger work to which reference has already been made.[22]

LOWER TRIASSIC SERIES

The formations of the general region assigned to the Lower Triassic outside the Portneuf quadrangle include 3,850 to 5,350 feet of shale, calcareous beds, and sandstone grouped in three units, of which the Woodside shale and Thaynes group are fossiliferous at certain horizons. The age determination is based upon ammonite zones, which occur 1,000 to 2,250 feet above the top of the Paleozoic formations. The fossils of the overlying 3,100 feet of sediments are less distinctive, and the faunal relations of some of them have not been fully studied. It is therefore possible, though perhaps not probable, that some of these strata may be of later age than Lower Triassic. The Timothy sandstone, the third member of the series, has thus far yielded no determinable fossils. The thicknesses here given for the Portneuf quadrangle are somewhat greater than those for the general region.

WOODSIDE SHALE

The principal exposures of Woodside shale in the Portneuf quadrangle are in secs. 25 and 36, T. 5 S., R. 38 E.; in a belt extending southeastward from sec. 21, T. 5 S., R. 39 E., into sec. 7, T. 6 S., R. 40 E.; and in several large areas in T. 5 S., R. 40 E. The rocks are characteristically platy calcareous shale with some limestone. They are usually distinct lithologically from the underlying Phosphoria formation but pass upward conformably into an overlying group of generally similar beds from which they are distinguished chiefly on the basis of the contained fossils, although there are some lithologic differences.

The Woodside shale as a whole is characterized by olive-drab platy shale with alternating thin beds of brownish-gray limestone that have locally a faint purplish tint. The shale is siliceous and calcareous, so that it is hard and rings under the hammer. It weathers into rusty-brown, yellowish, or even black fragments that

[22] Mansfield, G. R., op. cit., pp. 372–373.

on breaking show the characteristic olive-drab color, often with dendrites. The limestone on weathering preserves the purplish-gray or brownish-gray color and assumes a sort of velvety surface. Topographically the Woodside is represented by rounded but steep slopes strewn with platy débris but with relatively few ledges. Near the top of the formation, however, there are massive limestone beds that contain abundant pelecypods and that locally form conspicuous ledges.

The thickness of the Woodside shale in the Portneuf quadrangle is about 2,000 feet.

The shale is sparingly fossiliferous, and the forms contained are poorly preserved. Linguloid brachiopods and pelecypods, chiefly of the genus *Myalina*, are occasionally found. The limestone at some horizons, especially in the upper part of the formation, is highly fossiliferous. A *Myalina* zone and a zone of brachiopods, chiefly species of *Terebratula*, occur just below the top of the formation and serve as convenient guides.

The age of the Woodside shale is somewhat in doubt. Its lithologic and faunal similarity to the deposits of the Thaynes group have caused it to be grouped with those deposits as Lower Triassic rather than with the Paleozoic rocks. Hence its base is provisionally regarded as the base of the Triassic in this region.

THAYNES GROUP

The Thaynes, which had formerly been considered a single formation, was designated a group by the writer [23] in connection with his studies in the Fort Hall Indian Reservation. Three formations—the Ross Fork limestone, the Fort Hall formation, and the Portneuf limestone—were differentiated on both lithologic and faunal grounds, and descriptions of them were published in the paper cited and in the writer's account of the Fort Hall Indian Reservation.[24] As an attempt has been made to differentiate the formations on the map (pl. 1), brief descriptions are given below. Collections from the Woodside shale and Thaynes group in the Portneuf quadrangle are very meager. For details regarding the faunas of these formations the reader is referred to the report just cited or to the writer's report on the general region.[25]

The Ross Fork limestone, which takes its name from Ross Fork Creek, in the Fort Hall Indian Reservation, lies conformably upon

[23] Mansfield, G. R., Subdivisions of the Thaynes limestone and Nugget sandstone, Mesozoic, in the Fort Hall Indian Reservation, Idaho: Washington Acad. Sci. Jour., vol. 6, pp. 31–42, 1916.

[24] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation: U. S. Geol. Survey Bull. 713, pp. 46–50, 1920.

[25] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 93, 94, 434–436, 1927.

the Woodside shale and includes at its base the "*Meekoceras* beds" of the Hayden Survey. These are gray to reddish-brown limestones about 50 feet thick that contain numerous ammonites, the chambered shells of which appear on the weathered surface of the rock. In this region the fossils do not weather out so readily and the beds are not so conspicuous as in the Georgetown district, farther southeast. Above the *Meekoceras* zone for about 800 feet are massive and thin-bedded gray to brown limestones which contain many brachiopods, chiefly *Pugnax* and terebratuloids, and pelecypods, *Myalina* and others, with intervening calcareous shales. The lithology of this part of the formation is much like that of the Woodside. The presence of a small brachiopod in the massive limestone near the base is a convenient guide where the *Meekoceras* zone is not available. The upper 500 feet of the Ross Fork limestone consists of a dense calcareous gray to olive-greenish shale that weathers brown to yellow. This shale forms conspicuous cliffs and is mainly nonfossiliferous.

The Fort Hall formation, named from the site of old Fort Hall on Lincoln Creek, in the Fort Hall Indian Reservation, is conformable with the Ross Fork limestone and at the type locality consists of four parts. At the base is a soft, sugary yellow calcareous sandstone, about 50 feet thick, which at one locality includes a bed of sandy limestone 15 feet thick containing a plicated oyster-like shell. Next comes about 100 feet of gray or yellowish siliceous dense limestone, which contains large pectinoids and irregular cherty nodules and streaks that weather with a rough surface and project along bedding planes. This limestone forms rough ledges and high points. The third part, observed only locally, is composed of about 50 feet of sandy and shaly gray limestone and includes an oolitic bed 6 to 10 feet thick. The remainder of the section, estimated to be about 600 feet thick, consists of yellow to grayish cherty and sandy limestones in thin beds, which are represented chiefly by fairly smooth slopes strewn with yellow and reddish sandy and cherty float fragments.

The Portneuf limestone, named from Portneuf River, near the head of which the formation is well exposed, is a massive siliceous and cherty gray to yellowish limestone. The chert occurs in rounded and elongated nodules and in streaks. Silicified fossils, including *Spiriferina* n. sp.?, *Terebratula semisimplex* and other terebratuloids, and *Myophoria lineata?*, project from the weathered surfaces. The formation is fairly resistant to erosion and is estimated to be about 1,500 feet thick. In the Lanes Creek, Freedom, and Montpelier quadrangles, farther east, a well developed red-bed member, which consists of interbedded red sandstones and shales and ranges in thickness from 200 to 1,000 feet, occurs in the midst of the Portneuf limestone. This was not recognized in the Fort Hall Indian Reservation.

In the Portneuf quadrangle the differentiation of the three formations above described is not so readily made as in the Fort Hall Indian Reservation. The boundary between the Ross Fork and the Fort Hall was drawn in the field where the thin, platy, and calcareous beds of the Ross Fork, which locally form strong ledges, are succeeded by thicker-bedded and softer yellowish sandstones that weather into pinkish or reddish rounded blocks. The thinner-bedded material at the top of the Ross Fork as here mapped contains many pectinoids, large and small. The large pectinoids are with little doubt *Aviculipecten idahoensis*, so that the particular beds mentioned should be assigned to the Fort Hall rather than to the Ross Fork. The lithologic boundary selected, however, is a much more readily recognized cartographic boundary, and its use does not materially misrepresent the actual distribution of the formations. The upper beds of the Fort Hall as here mapped are massive and cherty and in general similar in lithology to beds of the lower part of the Portneuf. The cherts of the upper part of the Fort Hall, however, are irregular, streaky, and sandy and are developed in greater abundance than in the Portneuf beds, in which they are more nodular. The Portneuf beds also are more massive and contain silicified fossils here and there which project from weathered surfaces. The red-bed member of the Portneuf, recognized in the Lanes Creek, Freedom, and Montpelier quadrangles, was not identified in the Portneuf quadrangle. The principal occurrence of the formation is in the slope southwest of Grizzly Creek, in T. 5 S., Rs. 39 and 40 E., where brush and aspen groves are very thick and exposures are poor.

The thicknesses of the respective formations of the Thaynes group as exposed in T. 6 S., R. 39 E., are approximately as follows: Ross Fork limestone, 1,800 to 2,600 feet; Fort Hall formation, 800 to 1,000 feet; and Portneuf limestone, 2,600 feet. The variation in thickness of the Ross Fork and Fort Hall is probably due in part at least to the intense folding which they have experienced. The thickness given for the Portneuf may be excessive because the structural features that include the Portneuf in the northwest part of T. 5 S., R. 40 E., are faulted and more or less concealed by later igneous and sedimentary rock.

TIMOTHY SANDSTONE

The Timothy sandstone is typically a somewhat sugary yellowish to grayish rock of generally uniform character in beds 1 to 3 inches thick or locally more massive. In some places it weathers with a pinkish tinge; in others beds assigned to this formation are reddish or purplish. It is usually less resistant to weathering than the limestone below or the grit above and hence occupies depressions or relatively smooth slopes, on which exposures are few and poor. The formation as exposed elsewhere in the region is, at least locally, unconformable upon the Thaynes group. The only occurrences of the Timothy in the Portneuf quadrangle are in the NW. 1/4 NW. 1/4 sec. 18, T. 5 S., R. 40 E., overlapping a little into adjacent sections. The breadth of the principal exposure and the dip shown at this locality suggest that the thickness of the Timothy may be as much as 2,000 feet. This estimate is probably excessive. The thickness in the Fort Hall Indian Reservation is only 800 feet, and the greater apparent thickness here may be due to the position of the beds in a deeply folded and somewhat faulted syncline.

TRIASSIC (?) FORMATIONS

The great thickness of the formations assigned to the Lower Triassic in the general region, the unconformity at the base of the Timothy sandstone, and the more marked unconformity below the Higham grit suggest that the Higham and the overlying Deadman limestone and Wood shale may be of later age than Triassic. Nevertheless, the full representation of Jurassic beds in the general region, together with certain similarities between the stratigraphic sequence of the Idaho section and that of sections in Wyoming and Utah have led to the view that these three formations represent Middle and Upper Triassic sedimentation, although no fossils have been found in them. In the larger work already mentioned [26] the writer has discussed these relations and has presented a table that shows tentative correlations of the Idaho formations with those at specified localities in Wyoming and Utah. In the Portneuf quadrangle only the Higham grit is exposed.

Higham grit.—The Higham grit is normally a coarse white gritty or conglomeratic sandstone, locally quartzitic, with subangular fragments or pebbles of quartzite. No other rock type has been observed as a constituent. The rocks weather pinkish and locally reddish or purplish. The material appears to have been derived from early Paleozoic or older quartzite. The grit is distinct lithologically from the other rocks of the region and is prominent topographically. It forms strike ridges that are marked by rough, craggy ledges in many places. The lower 10 to 20 feet at some localities, as on the North Fork of Boulder Creek, in the Freedom quadrangle, is fine grained, purplish or yellowish, and more or less ferruginous. The formation appears to lie conformably on the Timothy sandstone, but several features

[26] Mansfield, G. R., op. cit. (Prof. Paper 152), pp. 190–192, 373, 374.

suggest that the base of the grit probably marks a pronounced stratigraphic break. These are the abrupt and striking change in lithology from preceding formations; the strongly ferruginous character of the basal beds; and the southward thinning of the underlying Timothy sandstone.

The only exposures of the Higham grit in the Portneuf quadrangle are in a single area occupying parts of the SW. 1/4 sec. 7 and the NW. 1/4 sec. 18, T. 5 S., R. 40 E., where the formation is represented by perhaps 200 feet of beds. The overlying Deadman limestone and Wood shale are absent in the Portneuf quadrangle but are exposed in the Cranes Flat quadrangle.

JURASSIC SYSTEM

The Jurassic system in this general region is represented by the Nugget sandstone, the Twin Creek limestone, the Preuss sandstone, and the Stump sandstone, with an aggregate thickness of about 6,500 feet. None of these formations are exposed in the Portneuf quadrangle, and probably all are absent though they appear in the Cranes Flat quadrangle on the northeast.

CRETACEOUS SYSTEM

In the general region beds assigned tentatively to the Cretaceous system have been included in the Gannett group, which has been subdivided into five formations having an aggregate thickness of 3,300 feet, and younger rocks assigned unqualifiedly to the Cretaceous have been included in the Wayan formation, comprising 11,800 feet of beds. The rocks are nonmarine sediments composed of conglomerate, limestone, sandstone, and more or less carbonaceous shale. None of these, however, are believed to be present in the Portneuf quadrangle, but they underlie extensive areas in the Cranes Flat quadrangle.

CRETACEOUS OR TERTIARY ROCKS

In sec. 13, T. 6 S., R. 39 E., a conspicuous ledge of siliceous and cherty breccia is cut into a gateway by a small canyon, utilized by the road that runs northeastward from Chesterfield to Grizzly Creek and Blackfoot River. The breccia is well exposed on both sides of the gateway and consists of cherty material similar to that of the more massive facies of the Rex chert, solidly cemented by silica. The breccia is massive rather than bedded and weathers with a somewhat waxy-looking surface. A similar breccia occurs in sec. 20, T. 6 S., R. 40 E.; secs. 10, 3, and 4, T. 6 S., R. 39 E.; and secs. 19, 32, and 33, T. 5 S., R. 39 E. Breccia of this sort was first observed by the writer in 1913 in the SW. 1/4 SW. 1/4 sec. 17, T. 5 S., R. 38 E., in the Fort

Hall Indian Reservation. Later similar breccia was found at several places along the trace of the Bannock overthrust in the Montpelier quadrangle, and it is believed that the breccia in the last-named area at least is related either to the Bannock fault or to some associated fault. The date of the Bannock overthrust is not known closely, but it occurred during the mountain-building epoch that followed the deposition of the Wayan formation and preceded the deposition of the Wasatch—that is, during the Laramide revolution. The age of the breccia would therefore be late Cretaceous or early Tertiary.

TERTIARY SYSTEM

In the general region the Tertiary system is represented only by the Wasatch formation (Eocene) and the Salt Lake formation (Pliocene?). Of these only the Salt Lake formation is exposed in the Portneuf quadrangle.

PLIOCENE (?) SERIES

The Pliocene (?) rocks are in general massively bedded and relatively soft. They overlie unconformably all older formations with which they are associated.

Salt Lake formation.—As most commonly encountered the Salt Lake formation consists of light-gray, buff, or locally pinkish conglomerate, in which the matrix is white, relatively soft, loose textured, and calcareous. Most of the pebbles are of local materials and rather angular, though many are subangular or even rounded. There is a wide range in size, some of the boulders being 4 or 5 feet in diameter and many of the fragments less than an inch. (See pl. 6, *A*.) In the Portneuf quadrangle the materials consist chiefly of early Paleozoic rocks, the most conspicuous and most widely distributed being pebbles and boulders of Swan Peak quartzite. Hills covered with conglomerate of the Salt Lake formation are strewn with countless pebbles and boulders of sandstone, quartzite, limestone, and chert. Ledges are few and in general poorly exposed. The massive character of the formation is, however, well shown by an exceptional exposure in the NW. 1/4 sec. 6, T. 5 S., R. 39 E., 1 1/2 miles north of the Portneuf quadrangle, along the road from Ross Fork to the Blackfoot dam. (See pl. 6, *B*.) Ordinarily the hills underlain by the Salt Lake formation are smoothly rounded (pl. 3, *C*), though valley sides cut in it are steep in many places.

In addition to the conglomerate there are beds of white marl, calcareous clay, sandstone, grit, and volcanic ash. In the Portneuf quadrangle a few areas of limestone and sandstone have been distinguished in the mapping. The conglomerate, however, is here the predominating representative of the formation. Soils weathered from the formation are commonly white or light colored.

A few fresh-water gastropods were collected from the Salt Lake formation in the Portneuf quadrangle. These proved to be undeterminable. In previous publications relating to the general region the Salt Lake formation has been tentatively referred to the Pliocene. No evidence has yet been found that necessitates a change in this reference.

The Chesterfield Range is largely underlain by the Salt Lake formation, though ledges and larger masses of older rocks emerge from cover here and there. Considerable areas in the foothills of the Portneuf Range are also underlain by these beds.

In the Fort Hall Indian Reservation large areas were mapped [27] as Tertiary or Quaternary upon the assumption that on many slopes where pebbles and boulders of the Salt Lake formation are strewn material of Tertiary age had been reworked and redistributed in Quaternary time. From wider experience in the general region the writer has concluded that most of these slopes are in reality developed upon Tertiary material and that they should be mapped accordingly. The mapping of the part of the reservation that lies within the Portneuf quadrangle has been changed to conform with this view.

The beds of the Salt Lake formation are as a rule nearly horizontal, though dips as high as 47° have been found locally. Some canyons cut in them are 750 feet or more deep. As the formation has experienced vigorous and protracted erosion the original thickness must have greatly exceeded this figure.

QUATERNARY SYSTEM

The rocks of the Quaternary system consist for the most part of unconsolidated gravel, sand, and mud that occupy the larger valley bottoms, and of coarser or finer débris, less well stratified, that has accumulated here and there along the lower slopes above the valley bottoms. Glacial deposits are absent, but there are a number of accumulations of travertine. The Quaternary deposits are all unconformable upon older rocks. For mapping they are divided into three groups, as described below.

PLEISTOCENE SERIES

Travertine.—White spongy or porous deposits of calcium carbonate have been formed at several places in the quadrangle by mineralized springs, some of which are still depositing, though on a reduced scale. The rock thus formed, which is called travertine, is

[27] U. S. Geol. Survey Bull. 713, pl. 3, 1920.

in some places coarse textured, open, or even cavernous (see pl. 3, *B*); elsewhere it is finer textured and harder. Locally it is stained yellowish or reddish by iron oxide.

Terraces of travertine at the mouths of Little Flat and Eighteenmile Canyons form rather striking topographic features. Another conspicuous area is in sec. 15, T. 5 S., R. 40 E., where a well-developed spring cone has been formed. (See pl. 7, *A*.) Other areas of some extent occur in secs. 29, 30, and 32 of the same township, in secs. 10 and 16, T. 6 S., R. 39 E., and along the east shore of Portneuf Reservoir from the SW. ¼ sec. 19, T. 6 S., R. 39 E., northwestward as far as the SE. ¼ sec. 11, T. 5 S., R. 38 E. There are a number of minor occurrences, some of which have not been mapped.

Hill wash and older alluvium.—The lower slopes of many of the hills are covered with rock fragments and soil that conceal the underlying formations. This material is in many places poorly assorted or without definite arrangement. Elsewhere it merges with fluviatile deposits and forms alluvial fans that have considerable areal extent. The upper limit of the deposits as mapped is the general line that marks the outcrop of the older, underlying formations, or the line where the débris of these rocks is sufficiently characteristic and abundant to indicate the strong probability of their occurrence beneath. The line is somewhat generalized, especially where it lies between the Salt Lake formation and the hill wash. The bouldery nature of the slopes underlain by the Salt Lake renders difficult or impossible any sharp distinction between the two formations. The lower limit, also somewhat generalized, is the line of demarkation of these deposits from those of the valley bottom, which are generally finer and better sorted.

The materials of the hill wash and older alluvium are mostly local or derived from near-by sources. They range in coarseness from boulders to fine soil and are usually not well rounded. The deposit has been cut away by stream action to a greater or less extent, so that the present surface is uneven, with low-lying spurs and interfingering depressions. The low-lying spurs and higher slopes of the deposit are generally covered with sagebrush where they have not been cleared for agriculture. Many of the depressions are grass covered, and those large enough to be separately indicated are mapped with the alluvium.

Some of the finer material mapped as hill wash has an uneven surface and probably represents accumulations of wind-blown dust such as those that have been recognized in the Henry and Cranes Flat quadrangles. The general characteristics of the hill wash indicate that it is a product of more arid climatic conditions than those of to-day.

The principal accumulations of hill wash in the Portneuf quadrangle are in the valleys of Corral and Grizzly Creeks and in Portneuf Valley. The alluvial fan on which Chesterfield is situated and that in the vicinity of Eighteenmile Canyon, both of which have been partly cut away by later erosion, are noteworthy. Fans also occur along the west side of Portneuf Valley. The thickness of the deposit differs from place to place. West of the mouth of Eighteenmile Canyon it probably exceeds 100 feet.

The climatic oscillations of the Quaternary period in southeastern Idaho have probably differed in degree rather than in character from those of the Bonneville Basin near Great Salt Lake as described by Gilbert. The epoch of deposition of the hill wash here is believed to correspond with Gilbert's pre-Bonneville epoch.[28]

RECENT SERIES

Alluvium.—In the broader valley bottoms and along the courses of many of the larger streams are narrow bands or broader areas of grassy meadow land with finger-like extensions up the tributary streams. The materials that underlie these areas are commonly well sorted and fine or locally gravelly. Along Blackfoot River there are stony flood-plain deposits. Elsewhere, as along Portneuf River, there are marshy areas of greater or less extent.

The principal area of alluvium is in Portneuf Valley northwest of a line that extends northeastward from the NE. ¼ sec. 26, T. 7 S., R. 38 E. The alluvial part of the valley is here about 6 miles wide. The northwest extension of this area, which is relatively narrow, is partly flooded by the Portneuf Reservoir. Areas of alluvium, which because of their situation above the general level of the valley may be called "perched," lie above the travertine deposits in Eighteenmile and Little Flat Canyons. In Grizzly Creek and its tributary Thompson Creek there is another fairly large area of alluvium.

Between the deposition of the hill wash and older alluvium and that of the alluvium here described there interposed an epoch of moister climate. No lacustrine stages such as those in Bear Lake Valley described by the writer [29] have been recognized in the Portneuf quadrangle, but it is believed that aside from this feature the physiographic development of this area is generally parallel to that of the broader area previously described and that the age of the alluvium may be considered Recent.

[28] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 221, 1890.
[29] Op. cit. (Prof. Paper 152), p. 30.

IGNEOUS ROCKS

GENERAL OCCURRENCE

Igneous rocks occupy considerable areas in two widely separated parts of the quadrangle. The southern part of Portneuf Valley, embracing more than 30 square miles within the area mapped, is occupied by a great field of basalt. The northern and northeastern parts of the quadrangle contain many exposures of both rhyolite and basalt. These exposures are scattered rather than continuous, and some are only a few feet across, but others occupy as much as 2 square miles. Some of the basalt is contemporaneous or nearly so with the rhyolite, but much of it is younger. A single occurrence of andesitic rock was noted. This is probably the oldest of the igneous rocks. Although beds of volcanic ash are well exposed in the Paradise Valley quadrangle, less than a mile north of the area here considered, such beds have not been recognized in the Portneuf quadrangle, and if present they are to be found in areas mapped as the Salt Lake formation.

HORNBLENDE ANDESITE PORPHYRY

Character.—In digging a prospect in the phosphatic shale in the SE. ¼ NE. ¼ sec. 30, T. 5 S., R. 40 E. (see p. 82), very much wealthered andesitic material was encountered at depths of 2 to 5 feet. The original andesite had decomposed into yellowish gravel, which now underlies and truncates the deformed phosphatic shale. The andesite had doubtless been intruded into the shale as a dike. Its extent and thickness were not determined. The weathered products resemble closely the similar weathered material of the hornblende andesite porphyry that is exposed at Sugar Loaf Mountain, in sec. 25, T. 2 S., R. 41 E., in the Cranes Flat quadrangle. The andesite is there seen in all stages from fresh rock to gravelly waste. Several dikes of generally similar rock are exposed in neighboring sections of the same township and in T. 2 S., R. 42 E.

The hornblende andesite porphyry in these localities is a gray crystalline rock that weathers pinkish, yellowish, or greenish. It is mottled with light or dark spots, which represent crystals of feldspar, hornblende, or biotite. The following petrographic description of a specimen from sec. 22, T. 2 S., R. 42 E., as kindly given by E. S. Larsen, shows the general character of a rock similar to that from which the weathered material in the Portneuf quadrangle is supposedly derived.

Macroscopically the rock is light gray and shows plagioclase phenocrysts as much as 1 centimeter across, prominent but smaller hornblende prisms, and a little biotite in a groundmass that has the appearance of a microgranular rock. The study of the thin section shows that the rock contains large phenocrysts of andesine and pale-green zoned hornblende. There are a few crystals of apatite with smaller crystals of plagioclase, biotite, and iron ore in a fine groundmass that is chiefly plagioclase but that probably includes some orthoclase and quartz.

Relative age.—In the general region the hornblende andesite porphyry has been found in contact with only two formations. In the Cranes Flat quadrangle it is associated with the Homer limestone member of the Wayan formation (Lower? Cretaceous), and in the Portneuf quadrangle it is intruded into the phosphatic shale of the Phosphoria formation. Its deeply weathered condition suggests that it is probably older than the other igneous rocks, none of which show so much alteration. Difference in weathering, however, depends upon so many variable factors that it may prove deceptive as a guide to the relative age of igneous rocks.

RHYOLITE

Character.—The rhyolite of the Portneuf quadrangle has not been studied separately from that of the general region. Many specimens from different localities in southeastern Idaho show little variation. According to Mr. Larsen their chief differences are textural. They probably represent closely related flows. They are nearly white to pale Quaker drab, pink, gray, or darker colored, rather porous fluidal rhyolites, which include a few crystals of quartz and orthoclase with a little plagioclase. They carry also a very little biotite, which is partly altered, besides zircon, apatite, and iron ore. In some parts of the region the rock is glassy, spherulitic, or pumiceous, but in the Portneuf quadrangle such rock is practically absent, though the glassy type is represented in a small exposure in the SW. ¼ sec. 11, T. 5 S., R. 39 E.

Distribution.—The rhyolite exposures are all in T. 5 S., Rs. 39 and 40 E. In some places, as in sec. 8, T. 5 S., R. 39 E., they consist of ledges barely protruding from the Salt Lake formation or forming low-lying points like rocky islands in that formation. In other places, as in secs. 18, 19, 20, and 21, T. 5 S., R. 40 E., the rhyolite forms masses of greater or less extent that overlie Triassic sediments. Elsewhere, as in secs. 11, 13, and 24, T. 5 S., R. 39 E., the rhyolite occurs in intimate association with basalt, with which it appears to be interbedded.

Mode of occurrence.—In all these occurrences the rhyolite is in the form of flows that lie nearly horizontal or dip as much as 25°. Although rhyolitic cones are prominent features of the landscape in the Henry quadrangle, on the east, none occur in the Portneuf quadrangle.

Thickness.—The thickness of the rhyolite differs locally, and its maximum has not been determined. In some places the flows are less than 50 feet thick; elsewhere valleys more than 200 feet deep have been excavated in them.

Relative age.—The rhyolite and hornblende andesite porphyry do not occur in proximity, and their relations to each other are unknown. From the much more weathered condition of the hornblende andesite porphyry it is believed to be the older. The relations between the rhyolite and basalt are relatively clear and indicate that the two rocks were, in part at least, practically contemporaneous, though some rhyolite is older than some basalt. The big rhyolitic cones south of the Blackfoot River Reservoir, in the Henry quadrangle, are practically surrounded by basalt. On the north slope of Middle Cone, in the same locality, ledges of basalt with inclusions of rhyolite and of rhyolite with inclusions of basalt have been found. In sec. 11, T. 5 S., R. 39 E., just north of the Portneuf quadrangle, the rhyolite has been intruded by basalt, as indicated by a small dike of basalt with chilled edges and vesicular center between plates of rhyolite.

OLIVINE BASALT

Character.—All the basalts of the region apparently contain olivine and may be classed as olivine basalts. There are many differences in the color and texture of the rock in the general region, but in the Portneuf quadrangle there is little variety in either texture or appearance. The rock may be described as aphanitic vesicular basalt. In thin section under the microscope, as described by J. F. Hunter, it is hypocrystalline, subophitic, and somewhat porphyritic, showing a few scattered phenocrysts of plagioclase, olivine, and augite. These are but little larger than the individuals of the groundmass. The groundmass is made up chiefly of laths of plagioclase, irregular grains of augite, olivine, magnetite, and a small amount of glass. The plagioclase has approximately the composition of labradorite.

Mode of occurrence.—Practically all the basalt exposed in the Portneuf quadrangle is in the form of flows. These occur either on top or on the sides of hills, where they are in many places slightly warped or tilted, or else in the valleys, where they are generally horizontal, though even here some exposures show pronounced dips. The disturbance of the hill basalts, however, has been due to earth movements, whereas that of the valley basalts is the result of flowage or of conditions accompanying the escape from the lava of imprisoned gases or vapors.

Thickness.—The thickness of the basalt doubtless varies considerably from place to place, especially where it was poured out over high ground, from which it would tend to run off. In the broad valleys, however, greater uniformity in thickness and greater thickness may be expected. In a well in the Henry quadrangle (sec. 30,

T. 7 S., R. 42 E.) basalt lying beneath 12 feet of soil and including two layers of red ash was at least 279 feet thick. In the Portneuf quadrangle well data are not available, but more than 100 feet of basalt is exposed in the canyon of Blackfoot River about a mile northeast of the quadrangle, where several flows may be recognized. (See pl. 7, *C*.)

Relative age.—The warped or tilted basalts that now lie on some of the hills are obviously older than the valley basalts, which have not been deformed. Thus there is evidence in the Portneuf quadrangle of at least two epochs of basaltic extrusion. Some basaltic eruptions on hilltops or hillsides in the general region probably belong with the later series. The earlier epoch was closely related to rhyolitic extrusion, as pointed out in the description of the rhyolite. The later epoch occurred after rhyolitic activity had ceased in the Portneuf quadrangle.

Source.—The older, hill basalts have come in part from local fissures, as indicated by the small basaltic dike mentioned in connection with the rhyolite, although no local fissures aside from the one occupied by that dike have been recognized. They may also have come in part from vents now more or less concealed by later flows or sediments. Some evidence of such vents occurs in the Paradise Valley quadrangle, on the north, where the basalt and rhyolite flows are associated with much reddish scoriaceous material similar to that which now forms basaltic cones in the adjoining Henry quadrangle.

The valley basalts in the Portneuf quadrangle are mostly extensions of the Blackfoot lava field, which occupies much of the Henry quadrangle and part of the Cranes Flat quadrangle. The basalt of Blackfoot and Corral Valleys, in T. 5 S., R. 40 E., came from the northern part of that field and at the time of its extrusion was fluid enough to cover wide areas with a practically horizontal surface. The basalt in Portneuf Valley may have come in part from craters situated a few miles south of the quadrangle, but if so flows from these sources were covered by the flood of lava that poured in from easterly sources through Tenmile Pass. The basalt, which, in a succession of flows, was dammed back along the east flanks of the Chesterfield Range and the Soda Springs Hills, found outlet through this pass and then deployed in a broad fan which heads at the pass and radiates forward into Portneuf Valley. A similar outpouring westward occurred at the gap occupied by Bear River at the south end of the Soda Springs Hills, but there the fanlike deployment of the basalt is not so evident.

Surface features.—The surface of the basalt in Portneuf Valley, though generally even, is marked here and there by broken mounds of basalt with steep outward radial dips and rude radial cracks, the whole probably representing former blisters 25 feet or more in diameter and 6 or 8 feet high on the surface of the formerly molten or viscous lava. Several of these occur in the vicinity of the southeast corner of sec. 31, T. 7 S., R. 40 E. The lines of sinks and other evidences of subterranean channels in the basalt that are common in the Henry quadrangle were not observed in the Portneuf quadrangle, and if present are covered with soil. Ledges and boulders of basalt are sufficiently abundant, especially in the southeastern part of the quadrangle, to make the roads rough in places.

Distribution.—The general distribution of the basalt has been outlined in the preceding discussion. The hill basalts in the Portneuf quadrangle are confined almost entirely to T. 5 S., R. 39 E. The valley basalts are exposed in T. 5 S., R. 40 E., and T. 7 S., Rs. 38 to 40 E.

RELATIONS OF IGNEOUS ROCKS TO SEDIMENTS

The hornblende andesite porphyry is intrusive into the Phosphoria formation. The rhyolite has been extruded upon Triassic formations and is interbedded with the Salt Lake formation. It is overlain here and there by hill wash. The older basalt, like the rhyolite, is interbedded with parts of the Salt Lake formation. The later basalts overlie the Salt Lake and earlier formations here and there and are themselves overlain in places by hill wash or wind-blown soil.

RELATIONS OF IGNEOUS ROCKS TO EACH OTHER

Details of the relations of the igneous rocks to each other have already been given. From the evidence presented in the Portneuf and Cranes Flat quadrangles it appears that the intrusion of hornblende andesite porphyry was not closely related to the other igneous activity of the region and may have been considerably earlier than the rhyolitic or the basaltic extrusion. Evidence from the Henry and Cranes Flat quadrangles taken in conjunction with that in the Portneuf quadrangle shows that an epoch of dominantly rhyolitic eruption preceded an epoch in which rhyolite and basalt were extruded with some alternation, which was followed by a time in which basalt was the dominant extrusive.

GENERAL IGNEOUS ACTIVITY OF THE REGION

The igneous activity of the Portneuf quadrangle has been summarized in the preceding paragraph. When the broader region of which this area forms a part is considered, the story is longer and more complex. The evidence seems clear for at least five epochs of igneous activity.[30] To this may be added the somewhat uncertain evidence of three other epochs. The latest phases of igneous activity thus far recognized seem to have been rhyolitic or latitic rather than basaltic. Elsewhere in southeastern Idaho, as in the Craters of the Moon National Monument, there are very late basaltic extrusions which may prove to be the youngest volcanic features of the region.

AGE OF THE IGNEOUS ROCKS

From evidence available in the region outside the Portneuf quadrangle it has been concluded that the hornblende andesite porphyry is probably not younger than early Pliocene and may be as old as early Eocene. The rhyolites and earlier basalts are closely associated with the Salt Lake formation and appear to represent products of igneous activity occurring in the later part of the epoch of deposition of that formation. As the Salt Lake formation is tentatively considered of Pliocene age the rhyolite and earlier basalt are also Pliocene (?). The later basalts, which occupy valleys developed in the Blackfoot cycle (see p. 7), are overlapped here and there by early Quaternary sediments and hence may be considered Pleistocene.

STRUCTURE

EARLIER GEOLOGIC WORK

The earliest geologic map that includes the Portneuf quadrangle is that by Peale, published in 1879, to which reference has already been made (p. 6). The field work on which this map is based was done in 1877.[31] Considering the fact that Peale made few direct geologic observations within the quadrangle his generalizations are surprisingly accurate. He noted, for example, that the structure of the upper Portneuf Valley is in part anticlinal[32] and that the hills in the northeastern part of the quadrangle are Jurassic.[33] These rocks are now considered Lower Triassic, but they were for a time grouped with the so-called "Jura-Trias." The main mass of the Chesterfield Range he correctly ascribed to the Carboniferous, and he noted the probability of synclinal structure between these Carboniferous rocks and the ridge now called Reservoir Mountain, in the adjoining Henry quadrangle on the east. He thought there were no faults because there was apparently room enough for the folds then recognized.

The principal errors of Peale's mapping in the light of more recent work are the designation of the rocks west of Portneuf Valley

[30] See U. S. Geol. Survey Prof. Paper 152, pp. 123–125, 1927.
[31] U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 511–646, 1879.
[32] Idem, p. 563.
[33] Idem, p. 596.

as Carboniferous, the omission of the Tertiary rocks that are abundant in the southern and central parts of the Chesterfield Range, and the failure to recognize the general complexity of the structure of that range.

Schultz and Richards [34] made little advance over Peale's mapping except the marking of faults along the northeast and southwest sides of the main ridge of the Chesterfield Range, which they considered a monocline with northwest trend and southwest dip. They correlated these faults with the Bannock overthrust of Richards and Mansfield.[35]

The writer's work in the Fort Hall Indian Reservation in 1913 [36] included parts of Tps. 5 and 6 S., R. 38 E., in the Portneuf quadrangle. The adjustment of this work to the later and larger-scale topographic map now available, together with some revision of field mapping and of interpretation, has been accompanied by appropriate changes in the geologic map here presented as Plate 1.

GENERAL FEATURES

The detailed work of 1913, 1916, and 1923 has shown that the geologic structure of the Portneuf quadrangle is far more complex than Peale supposed. The mountainous mass occupying more than the northeast half of the quadrangle and including parts of the Blackfoot Mountains, the Chesterfield Range, and the Soda Spring Hills contains no less than six major folds, all of which are cut to a greater or less extent by faults. The structure of Portneuf Valley is largely concealed by Tertiary and later sediments and by basalt, but from exposures along the northeast side there seems to be justification for Peale's view that the structure, in that part of the valley at least, may be anticlinal. The breadth of the valley farther south and the general complexity of the structure on the northeast suggest that the valley area may likewise be underlain by a number of large folds broken by faults. This suggestion is further strengthened by the evidences of folding and faulting in the foothills of the Portneuf Mountains along the west border of the quadrangle.

The folds east of Portneuf Valley trend generally northwest. Although they are apparently open and upright in some places, as seen in the geologic structure sections (pl. 2), they are elsewhere markedly inclined or even overturned northeastward. The trend of the folds west of Portneuf Valley is more directly north or even a little northeast, but the same tendency for eastward inclination is apparently present.

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[34] Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267–284, 1913.

[35] Richards, R. W., and Mansfield, G. R., The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, pp. 681–709, 1912.

[36] U. S. Geol. Survey Bull. 713, 1920.

One of the most remarkable structural features of the quadrangle is an overthrust fault that is believed to pass beneath the Chesterfield Range and Blackfoot Mountains and is locally eroded through, exposing rocks of the underlying block through a "window" in the upper block. Such features have been observed in connection with the Bannock overthrust. It is therefore concluded that this fault is either a part of the Bannock overthrust or of a closely related thrust fault. Other faults of presumably more recent date have dislocated parts of the folds contained in the upper thrust block and have doubtless affected the underlying block as well. All these faults have an important bearing on the commercial availability of the phosphate rock associated with the folds.

Another noteworthy feature of the quadrangle is the remarkable extension of Tertiary and later cover that conceals the structure over large areas. Fortunately, sufficient data are available, even in areas rather completely covered, to afford a basis for structural inferences that are probably true in a broad way.

STRUCTURE CONTOURS

As classification of phosphate lands is dependent in part upon the depth at which the phosphate occurs, it has been deemed advisable to show as far as practicable by structure contours on the map the approximate position of the phosphate beds beneath the surface. In this rugged region the altitude of the surface changes so greatly from place to place that it was thought best to use sea level as a datum plane. The structure contours were therefore drawn by projecting to the surface at the lines of the structure sections the successive positions of the top of the phosphatic shale member of the Phosphoria formation at altitudes ranging from 3,000 to 6,000 feet above sea level and connecting the points at each altitude. The lines thus drawn are necessarily very much generalized, but they serve to show approximately the areas within which phosphate may presumably be found at accessible depth. The approximate depth of the phosphate at any place along a structure-contour line may be found by subtracting the figure which designates that structure contour from the figure which represents the surface contour at the same place.

DETAILED DESCRIPTIONS

The detailed descriptions that follow are based on the geologic structure sections given in Plate 2. The folds are treated in order from northeast to southwest. Much of the faulting is discussed in connection with the folds, but independent consideration is given to the Bannock overthrust and to certain other faults.

Corral Creek anticline.—The principal fold in the northeast corner of the Portneuf quadrangle is the Corral Creek anticline, named from Corral Creek, which joins Blackfoot River at the west base of the ridge that forms the west limb of the fold. This fold, which has a width of about 2 miles, emerges from cover near the center of sec. 15, T. 5 S., R. 40 E., continues northwestward about 4½ miles, and passes again beneath cover in the Paradise Valley quadrangle. It is upright and symmetrical but is broken along its west flank in Blackfoot Valley by a fault, believed to be normal, that brings the Portneuf limestone on the west into contact with the lower part of the Ross Fork limestone on the east. The downthrow to the west at the line of structure section A–B is estimated at about 4,000 feet, whereas at the line D–E it is about 2,000 feet. Thus the throw of the fault appears to diminish southeastward. On the east side the Corral Creek anticline adjoins a syncline that extends from the Paradise Valley quadrangle into the Cranes Flat and Henry quadrangles and is thought to be the continuation of the Reservoir syncline of the Henry quadrangle.

The Corral Creek anticline pitches toward the northwest at an average rate of about 725 feet to the mile. It has commercial importance in that it makes valuable phosphate deposits relatively accessible. It is supposedly cut at unknown depth by the Bannock overthrust.

Nigger Creek syncline.—Immediately southwest of the Corral Creek anticline there is a syncline whose surface is drained in part by Nigger Creek. This fold may therefore appropriately be called the Nigger Creek syncline. It enters the area of the Portneuf quadrangle beneath cover from the southeast and its extension in that direction is unknown. Its presence at the line of structure section F–G is inferred from the attitudes of the Ross Fork limestone and Fort Hall formation in areas half a mile or more north of this line. Within the Portneuf quadrangle the fold has a curving trend toward the northwest for a distance of about 7 miles. In secs. 17 and 18, T. 5 S., R. 40 E., it is offset by a transverse fault with downthrow to the north. This fault, which is entirely concealed, must exist, for the Portneuf limestone occurs on the north side of Nigger Creek in the strike of the Ross Fork limestone on the south side. The fault is believed to be normal and to be related to the strike fault that cuts off the west flank of the Corral Creek anticline. The Nigger Creek syncline is offset by a second cross fault in sec. 7, T. 5 S., R. 40 E., by which Portneuf limestone on the north is brought upward with respect to Timothy sandstone and Higham grit on the south. A short distance north of this fault the fold passes beneath cover which continues far into the Paradise Valley quadrangle. The east side of the fold for at least part of its course is marked by the strike fault above mentioned.

At the line of structure section F–G the Nigger Creek syncline is little more than half a mile wide, and the uppermost of the pre-Tertiary beds in it presumably belong to the Fort Hall formation. It is believed to be unsymmetrical, with eastward inclination of its axial plane. At the line of structure section D–E the fold is somewhat wider, and its unsymmetrical character is clearly shown, the west limb being strongly overturned toward the northeast. At least one minor anticlinal fold is there developed in its troughlike bottom. The Fort Hall formation still comprises its uppermost pre-Tertiary beds. At the line of structure section A–B the fold is as much as 2 miles wide and its uppermost beds, though concealed, are believed to be the Timothy sandstone, for the Higham grit, next above the Timothy, is exposed within about 100 yards north of the line of the section. The greater width and higher stratigraphic content of the fold at this line are believed to be due in part to the combined influence of the fault in Nigger Creek and of the strike fault, which it joins. Both of these faults produce a greater downthrow toward the northwest. This effect may also be due in part to a gentle northwesterly pitch.

The Nigger Creek syncline, like the Corral Creek anticline, is believed to be cut off at unknown depth by the Bannock overthrust. Even without this disadvantage the Nigger Creek syncline is so deep that the phosphate beds that would normally underlie it would be too deep to be considered commercially available.

Grizzly Creek anticline.—The Grizzly Creek anticline enters the Portneuf quadrangle beneath cover in about secs. 22 and 15, T. 6 S., R. 40 E., and extends southeastward from this area under cover an unknown distance. Within the Portneuf quadrangle it has a generally northwest trend for 9 miles or more and probably extends a considerable distance into the Paradise Valley quadrangle, but for much of its course it is concealed by Tertiary or later beds and by igneous rocks. It is named from Grizzly Creek, which follows the general strike of the fold.

The position and character of this fold at the line of structure section F–G are inferred from exposures of Triassic formations a quarter of a mile and more north of the line. It is about a mile wide and is presumably inclined eastward here, as it is farther north.

At the line of structure section D–E the fold is about 2 miles wide and its crest is broken by a fault. This fault, which is believed to be normal, has a downthrow to the southwest estimated at nearly 2,500 feet. It is nowhere exposed but is covered by Quaternary sediments, by weathered products of the formations affected, or by igneous rocks. Several areas of travertine along the northeast side of the valley of Grizzly Creek are thought to indicate the approximate position of its trace. There is no evidence of its presence near the line F–G, so it doubtless originates somewhere between F–G and D–E. Likewise it dies out northwestward. Its maximum throw is reached at about the line D–E, where beds of the upper part of the Woodside are brought into contact with beds of the middle to the upper part of the Wells.

The undue width of the strips of territory occupied by Ross Fork limestone southwest of the fault and by Woodside shale northeast of it is explained by drag folds near the crest of the fold, which are necessitated by the sharp changes in dip near the contact of the Woodside and Ross Fork at the southwest and within the Woodside at the northeast. Such drag folds within larger folds have been recognized and were photographed at a number of places in the quadrangles on the east and southeast previously mapped by the writer and his associates.[37] Their presence in an area so strongly folded as the Portneuf quadrangle is therefore to be expected.

The Grizzly Creek anticline brings to the surface the phosphatic shale member of the Phosphoria formation for a distance of about 2 miles along the northeast side of the valley. The phosphatic shale occupies depressions just back of a series of rocky knolls, and in 1916 was prospected by the Geological Survey party. (See p. 82.) The adjacent Nigger Creek syncline is so deep that the phosphate beds descend steeply into it. Hence the area in which they may be regarded as accessible by mining is relatively narrow.

At the line of structure section A–B the Grizzly Creek anticline is little more than a mile wide. The area occupied by the Ross Fork limestone as projected beneath cover to the line of the section is apparently too narrow to allow for the double thickness of this formation necessitated by the fold. It is believed, therefore, that the fault already discussed in connection with structure section D–E is also present here but with much diminished throw.

This fold appears to have reached its maximum development at about the line of structure section D–E, where the crest was arched higher than elsewhere and where correspondingly lower beds were exposed. The extra width of the fold near this line is due not only to the arching mentioned but also to the faulting above described.

The Grizzly Creek anticline is economically important because of the phosphate beds that it contains. These are accessible in the higher parts of the arch, as already explained, but toward the north and the south they would normally lie too deep to be commercially available. There is the further probability that the phosphate in

[37] See U. S. Geol. Survey Prof. Paper 152, pls. 48, *B*, and 50, *B*, 1927.

the deeper portions of the fold may be cut out by the Bannock overthrust.

Graves Creek syncline.—The next fold in order southwest of the Grizzly Creek anticline is the Graves Creek syncline, named from Graves Creek, which has excavated a valley in its southwest limb. This fold enters the Portneuf quadrangle beneath cover in about the NE. 1/4 sec. 27, T. 6 S., R. 40 E., southeastward from which it extends beneath cover an unknown distance. Within the quadrangle it extends northwestward about 4 miles before emerging, and at a distance of about 9 1/4 miles it again passes beneath cover. There is every reason for believing that it continues well into the Paradise Valley quadrangle, but its northwestward extension has not been identified.

At the line of structure section F–G the position and character of the Graves Creek syncline can be inferred only from the position and attitude of the Wells formation, which there constitutes part of its southwest limb and dips southwestward, and from conditions indicated by structure section C–D–E on the northwest. At line F–G the fold is only about a mile wide, whereas farther northwest it is considerably wider. It is therefore likely that the syncline dies out toward the southeast, or perhaps it is affected by cross buckling or warping in that direction.

At the line of structure section C–D–E the Graves Creek syncline is about 2 miles wide, and its axial plane is inclined strongly northeastward. The highest beds contained in it belong to the Portneuf limestone, of which only the lower member appears to be represented. About a mile southeast of the point marked D in the section the Fort Hall formation seems to transgress the Ross Fork limestone, suggesting the presence of a minor thrust fault in that part of the fold. The Phosphoria formation with its phosphate beds is exposed along the southwest flank of the syncline. This formation is here overturned and dips southwestward at an angle of about 50°. In the trough of this fold the phosphate beds would normally lie too deep to be considered available for mining.

At the line of structure section A–B the Graves Creek syncline is 2 miles or more wide and, though inclined eastward, as at the line C–D–E, seems to be less closely compressed, perhaps because the fault dies out in the adjacent Grizzly Creek anticline. The Phosphoria continues to be exposed along the southwest limb, and the highest beds are Portneuf. Although none of the red beds of the Portneuf have been recognized here, the lower member is thought to be somewhat more fully preserved than at the line C–D–E. The greater width of the syncline at C–D–E and A–B than at F–G, together with the presence of successively higher beds toward the northwest, indicates that the syncline pitches gently in that direction, though it has not been practicable to measure the rate.

The lower part of the Graves Creek syncline is with little doubt cut off by the Bannock overthrust, which locally rises to the surface in the next fold to the southwest. One effect of this fault, so far as this syncline is concerned, is to make very doubtful the existence of phosphate in normal position in its deeper parts.

Twentyfourmile anticline.—The name of the Twentyfourmile anticline is taken from Twentyfourmile Creek, which, with its East Fork, has excavated valleys along both limbs of the fold for a number of miles. This is the largest fold in the Portneuf quadrangle, and because of its intimate relations with the Bannock overthrust it is in some respects also the most interesting structural feature in the quadrangle.

The line of structure section H–I has been extended to include exposures of the Brazer limestone in the adjoining Henry quadrangle. These exposures clearly indicate that the general structure observed farther northwest continues southeastward into the Henry quadrangle. Unfortunately the fold passes beneath cover in that direction beyond the first mile or two. In the Portneuf quadrangle, too, it is largely concealed by Tertiary beds, which lie unconformably upon the eroded older strata. After continuing northwestward about 14 miles from the line H–I the anticline passes beneath cover, perhaps to reappear in one of the broken folds of the Fort Hall Indian Reservation beyond, but its identity in any extended portions has not been established. Upon the assumption that at the line H–I it is a closely folded anticline overturned toward the northeast, an assumption which seems justified from conditions farther northwest, the Twentyfourmile anticline would be nearly 2½ miles wide where it enters the quadrangle, and the lowest beds exposed in it would be beds of the Brazer limestone.

At the line of structure section F–G the conditions are somewhat similar. Only the Wells formation, which makes up part of the northeast limb, is exposed, but the southwesterly dip of these beds, about 35°, indicates clearly that the fold is strongly overturned toward the northeast. The arched plane of the Bannock overthrust is supposed to rise near the surface at this line and perhaps even to have been exposed by the erosion of the fold, but, if this is true, the exposure has been concealed by the deposition of the Salt Lake formation. From the occurrence of the siliceous fault breccia indicated on the map by the symbol KTb at places within 1 mile southeast of the line F–G and 1½ miles northwest of this line it is thought that the upper block of the Bannock overthrust may be broken through or faulted along the crest of the arched thrust plane. This interpretation is indicated in the structure section.

At the line of structure section C–D the Twentyfourmile anticline is about 3½ miles wide. The northeast limb is fully exposed and also a small part of the southwest limb. The dips of the beds in the two limbs are roughly parallel, about 40° SW., so that the fold as a whole is strongly overturned toward the northeast. The most interesting feature of the fold at this line is the occurrence in the midst of it of massive ledges undoubtedly belonging to the Rex chert member of the Phosphoria formation and surrounded on all sides by Brazer limestone. The chert dips southwestward somewhat more strongly than the inclosing limestone. It is this occurrence which, as above stated, has led to the view that the Bannock overthrust or some related fault with folded thrust plane underlies the Chesterfield Range. The Bannock overthrust is more fully described on page 55.

At the line of structure section A–B the anticline is a little narrower than at C–D and has about the same degree of northeastward overturning. The lower block of the Bannock overthrust is not exposed, but its presence near the surface is suggested by the ledges of cherty fault breccia along the crest of the arched Brazer limestone at places intermediate between the exposure of Rex chert noted above and the line A–B and by the similar ledge in the SE. ¼ sec. 19, T. 5 S., R. 39 E., 1½ miles northwest of that line. These exposures seem to indicate a more or less continuous break in the limestone along the line supposedly marking the trend of the arch in the folded thrust plane. This interpretation is indicated on the map and in structure section A–B.

The group of structure sections above reviewed seems to indicate that the Twentyfourmile anticline originates at a point some distance southeast of the place where the fold enters the Portneuf quadrangle. It pitches on the whole rather gently northwestward but is wider and more deeply eroded at the line C–D than elsewhere. This effect may be due to a slight upwarping of the axis of the fold at that place, but the upwarping is not sufficient to disturb the strike of the beds along the exposed northeast limb of the fold except to a very minor degree.

Phosphate beds are exposed for about 5 miles along the northeast flank of the anticline and locally along the southwest flank. It is believed that they follow both sides of the fold beneath cover. Their actual position in these places would have to be determined by drilling, but their approximate positions may be inferred from the measured dips and the known thicknesses of the rock formations. Because of the presence of the Bannock overthrust beneath at least certain parts of the fold the beds, which descend steeply, are in all probability cut off at moderate depths in such places.

Rock Creek syncline.—Southwest of the Twentyfourmile anticline the structure of the underlying rock is largely concealed by

Tertiary beds, but exposures here and there indicate the presence of at least one more large fold. The largest exposed area is in the vicinity of Rock Creek in the southeast corner of T. 5 S., R. 38 E. The fold with which these exposures are chiefly connected may therefore appropriately be called the Rock Creek syncline.

The presence of this syncline at the line of structure section H–I is inferred from the exposures of older Paleozoic rocks in eastward ascending order along the west base of the Chesterfield Range north of Tenmile Pass and of the Brazer limestone along the line H–I (extended) in the adjoining Henry quadrangle. The indicated structure is postulated from the measured dips and from the known thicknesses of the formations involved. It is believed that this fold passes southeastward an unknown distance under cover. At the line H–I it is about 2 miles wide. The depth of the syncline is unknown, but a reasonable interpretation of the available data shows that the Phosphoria formation and some of the lower beds of the Woodside are probably present. The actual position of the phosphate beds in this part of the fold can be determined only by drilling, but their approximate position is shown in the structure section.

At the line of structure section F–G the Phosphoria and Wells formations are exposed with gentle northeasterly dips near the west end of the line, and the Wells formation with steeper westerly dips appears near the middle. On the basis of the known folds farther northeast, of which the last-named Wells exposures are presumably a part, there is little, if any, room for beds higher than the Phosphoria in the Rock Creek syncline at the west. Thus the syncline is supposed to be relatively shallow and broadly opened.

At the line of structure section C–D the Rock Creek syncline is largely concealed by Tertiary beds, and its shape and character are inferred on the basis of available measurements of dip and thickness and the structure of neighboring beds on the east. The presence of a subsidiary anticline within the syncline is suggested by the folded and faulted condition of the syncline farther northwest and by the fact that the scattered exposures of Rex chert and Woodside shale within a mile to the northwest of the line C–D appear to indicate a shallow rather than a deep fold. The west limb of the syncline is slightly faulted and overturned toward the northeast.

At the line of structure section A–B the Rock Creek syncline is affected by shallow minor folds, some of which may be of the drag fold type, and by faulting. There are two synclinal axes, which presumably join farther northwest beneath cover, with an intervening anticlinal axis. The faults, which appear to include both normal and reverse types, do not create great displacements, though they introduce considerable complexity into the mapping, especially in sec. 6, T. 6 S., R. 39 E. The character and direction of the minor folds are indicated by axes drawn on the geologic map. The narrowing of the Rock Creek syncline, as outlined by exposures of phosphatic shale at Rock Creek in sec. 31, T. 5 S., R. 39 E., suggests a local transverse warping of the fold in the manner tentatively indicated on the map.

The Rock Creek syncline apparently deepens and widens toward the northwest and is doubtless represented by one of the folds in the Fort Hall Indian Reservation, but the structure in the intervening areas is concealed. This fold has some importance as a possible commercial source of phosphate, of which the most readily accessible beds are those in the areas immediately adjoining Rock Creek. It is thought that phosphate would probably be found beneath cover along the trend of the axis as indicated on the map, but its depth, extent, and character could be determined only by boring.

Other folds.—The southwest ends of the structure-section lines all show strata dipping in such a manner as to constitute the northeast limb of an anticline, the crest of which would lie beneath cover near the eastern border of Portneuf Valley. This mapping supports Peale's view of anticlinal structure at the north end of the valley. If no significant faults exist other folds similar to those above described doubtless underlie Portneuf Valley.

The foothills of the Portneuf Mountains west of Portneuf Valley, so far as they extend into the Portneuf quadrangle, include only parts or fragments of folds. The beds exposed are all of Cambrian and Ordovician formations with general easterly dips, and the stratigraphic succession rises in general in that direction.

The Swan Peak quartzite in sec. 35, T. 7 S., R. 38 E., and sec. 1, T. 8 S., R. 38 E., lies in a syncline in which the axis strikes northwest and the west limb dips more steeply than the east limb. The exposures of Swan Peak quartzite in secs. 23, 13, and 14, T. 7 S., R. 38 E., suggest similar structure, but here the east limb as represented by the knoll in secs. 13 and 14 dips more steeply.

The Cambrian beds on the south side of Topons Creek have synclinal structure.

Bannock overthrust.—The name Bannock overthrust was originally given by Richards and Mansfield [38] to a group of thrust faults, which, upon detailed study, seemed to mark the edge of a great block or slice of the earth's crust that had moved east-northeastward with respect to underlying rocks for possibly 35 miles or more. Starting in northeastern Utah the sinuous course of this overthrust was traced northward and northwestward intermittently for about 270 miles. Much of the faulted area lies in the group of seven quadrangles east

[38] Richards, R. W., and Mansfield, G. R., Jour. Geology, vol. 20, pp. 681–707, 1912.

and southeast of the Portneuf quadrangle described in the author's larger work,[39] and the reader is therefore referred to that publication for a detailed description of this great structural feature. In the paper cited suggestion was made of a possible connection between the Bannock overthrust and the Putnam overthrust of the Fort Hall Indian Reservation.[40]

One of the remarkable characteristics of the Bannock overthrust is the fact that its thrust plane is systematically warped or gently folded so that the overlying block is cut through here and there by erosion, thus exposing the rocks of the underlying block. The exposure of the Rex chert in the midst of Brazer limestone in the canyon of the East Fork of Twentyfourmile Creek in sec. 10, T. 6 S., R. 39 E., in the Portneuf quadrangle, is thought to be similar evidence of the presence of the Bannock overthrust plane beneath the Chesterfield Range. The alternative supposition, that the chert ledges are an eroded remnant of a fault block let down into its present position, has little to support it. The occurrence of a great thrust fault in the western parts of Tps. 3 and 4 S., R. 40 E., in the Paradise Valley quadrangle, on the north, is believed to strengthen the view first stated. The ledges or masses of Cambrian rocks in sec. 18, T. 5 S., R. 39 E., to which reference was made on page 19, lie on both sides of the line (extended) which has already been mentioned as marking the position of ledges of siliceous fault breccia presumably associated with the Bannock overthrust. It therefore seems highly probable that these occurrences are ledges of Cambrian rocks and that they are definitely related in some way to the Bannock overthrust, either as a part of the upper block or as a slice of older rock heaped upon the upper block by a subsidiary thrust fault. The thick cover of Tertiary sediments, however, effectually conceals the structure in the vicinity of these ledges.

In sec. 20, T. 5 S., R. 38 E., in the Fort Hall Indian Reservation, there is a thrust fault, part of the Putnam overthrust, that brings Cambrian and Ordovician rocks into contact with Wells and Phosphoria beds. This fault, which passes under cover both eastward and westward with only scant exposure, is now believed to represent a westward extension of the fault zone of the Bannock overthrust. The relations of the Putnam overthrust and of the window in the Portneuf quadrangle to other parts of the Bannock overthrust are shown in Figure 2. The window and the axis of the Twentyfourmile anticline lie in the northwest extension of the axis of an anticline in the fault plane previously mapped on the basis of evidence in

[39] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 1927.

[40] See also Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, pp. 62–65, 101–102, 1920.

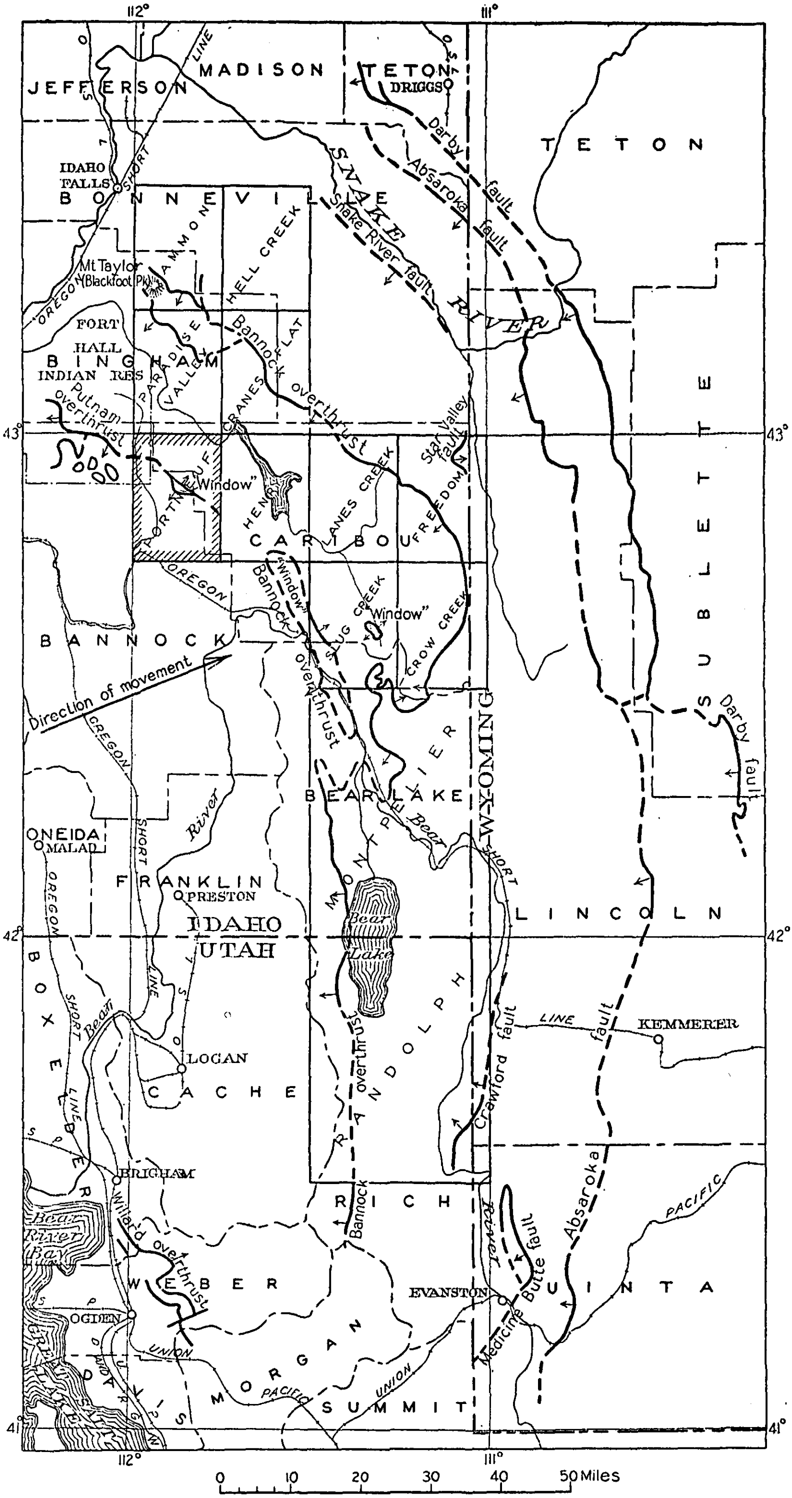

FIGURE 2.—Sketch map of part of the Bannock overthrust, showing its relations to the Putnam overthrust and to later-mapped portions in the Portneuf, Paradise Valley, and Ammon quadrangles. Short arrows show dip of fault planes

Bear River Valley near Nounan and southeast of Soda Springs. The branches shown in the Paradise Valley and Ammon quadrangles were mapped in 1923 and 1925.

The eastern edge of the upper block of the Bannock overthrust as thus far mapped passes northwestward through the center of the Cranes Flat quadrangle and continues thence into Taylor Mountain (Blackfoot Peak), about 25 miles north of the Portneuf quadrangle, where St. John[41] many years ago recognized evidences of faulting. The western edge of the thrust plane or the line of origin of the fault has not been found. Indeed, it is doubtful if even detailed work will bring it to light unless through some fortunate combination of circumstances. Doubtless it lies some distance west of the Portneuf quadrangle. Possibly the hot springs (Lava Hot Springs) and travertine terraces in Portneuf Canyon, 8 miles or more south of the southwest corner of the Portneuf quadrangle, may have some bearing on the question.

The Bannock overthrust passes beneath cover of Tertiary sediments and lavas in T. 1 S., R. 38 E., in the Ammon quadrangle. A fault of similar habit is reported by Kirkham[42] on the Continental Divide near Medicine Lodge Creek. This lies in the strike of the Bannock overthrust and is intermediate in position between that fault and the Philipsburg faults previously described by Calkins,[43] with which it is also in line. Possible connections of these faults with one another and with other great overthrusts farther north are thus suggested.

The Bannock overthrust is introduced into the structure sections A–B to H–I, Plate 2, without attempt to indicate its position otherwise than to mark its rise to the surface in the Twentyfourmile anticline. Some undulation in the fault plane is to be expected in view of its known flexures in the region farther east. Its relation to the folds of the upper block is purely conjectural. No information regarding the nature of the underlying block is available except the occurrence of the chert ledges above mentioned and of the Triassic and Jurassic beds that emerge from beneath the upper block in Tps. 3 and 4 S., R. 40 E., in the Paradise Valley quadrangle. The occurrence of these rocks suggests that the underlying block is composed of Paleozoic and Mesozoic rocks much like those of the upper block. Their constitution and structure at any given place, however, are indeterminable except by drilling.

The effect of the Bannock overthrust upon the occurrence and accessibility of phosphate beds is with little doubt to cut off the

[41] St. John, Orestes, U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 340, 341, 356, 1879.

[42] Kirkham, V. R. D., personal communication.

[43] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, p. 146, 1913.

bottoms of the deeper phosphate-bearing synclines and to render generally indeterminate the position of possible phosphate beds in the lower block.

Other faults.—Most of the faults mapped in the Chesterfield Range have already been described in connection with the description of the folds with which they are associated. A rather persistent fault of small throw, presumably a minor thrust, extends southeastward from sec. 1, T. 6 S., R. 38 E., and disappears beneath cover in sec. 17, T. 6 S., R. 39 E. It follows the phosphatic shale of the Phosphoria formation, which it cuts out completely at some places. It is offset by a normal fault in the SW. ¼ sec. 6, T. 6 S., R. 39 E., and by two small transverse faults in sec. 7. A similar and possibly related fault cuts out the phosphate beds in the SE. ¼ sec. 25 of the same township.

The complex of faults in sec. 6, T. 6 S., R. 39 E., and sec. 31, T. 5 S., R. 39 E., has been mentioned briefly in the discussion of the Rock Creek syncline. They probably include both normal and reverse types. Their relations are not fully understood but are thought to be correctly represented within the limitations imposed by time and scale.

The Little Gray fault of the Henry quadrangle, one of the transverse normal faults that there produces marked geologic and topographic effects, may enter the Portneuf quadrangle. If so, it either dies out or is cut off by the fault that separates the Nigger Creek syncline from the Corral Creek anticline. It is represented on the map in sec. 15, T. 5 S., R. 40 E., merely as a suggested extension. The Pelican fault of the Henry quadrangle has not been identified in the Portneuf quadrangle, but there are some suggestions that it may be present. (See p. 87.)

Reference has been made (p. 46) to the mapping of a fault by Schultz and Richards along the west base of the Chesterfield Range, which they thought might be related to the Bannock overthrust. The possible extension of the Bannock overthrust in this region has already been discussed. There remains the question of possible normal faulting along the west base of this range.

At two places the western slope of the range is marked by a steep rocky ridge composed of Paleozoic rocks, which represent the east limb of an anticline whose west limb, if present, must lie beneath the later cover of the floor of Portneuf Valley. The general abruptness of the west slope in each of these ridges is noteworthy and in itself suggestive of faulting, but no fault breccia and no slickensides have been observed in confirmation of the suggestion. On the other hand, there are two very striking features in the southern ridge that give support to the idea of faulting. These are the travertine terraces that form such conspicuous ledges at the mouths of Little Flat and Eighteenmile Canyons, in T. 7 S., Rs. 39 and 40 E. (See pl. 3, *B*.) Although travertine terraces are not a feature of the landscape in connection with the northern ridge, there is a considerable mass of this material more or less concealed by hill wash near the base of this ridge and exposed for nearly 3 miles northwestward from the dam on the northeast shore of Portneuf Reservoir.

Another line of evidence is suggestive in this connection. The lowest beds exposed just north of Monroe Canyon, in T. 7 S., R. 40 E., belong to the Laketown dolomite, and the series of formations descends stratigraphically westward. Structurally the beds are rising westward toward an anticlinal axis, and the next formations in order should be of Ordovician and Cambrian age. These beds, together with the overlying Devonian and Carboniferous formations, are normally resistant to erosion and form generally rugged topography. It is therefore strange that the west flank of the ridge should cease so abruptly and that these resistant formations should be low enough to be concealed by Quaternary sediments and basalt unless they had been dropped down by faulting. On the whole the idea of a normal fault with downthrow to the west along the west base of the Chesterfield Range is believed to be justified, although direct evidence of its presence is lacking. It is therefore tentatively represented on the map.

With southwestward-dipping normal faults both to the northeast and to the southwest the Chesterfield Range would seem to be a horst—that is, an eroded fault block composed of folded and faulted older strata, standing relatively higher than neighboring blocks on both sides.

Reference to faults in the foothills of the Portneuf Mountains west of Portneuf Valley has already been made in the discussion of the Cambrian and Ordovician formations. The most noteworthy of these faults is the one followed by King Creek, which causes the Cambrian beds on the north side of the creek to be offset about half a mile eastward with respect to those on the south side. The fault is presumed to be normal with the downthrow on the south side. The dips of the beds on opposite sides of the fault differ, those on the south side being somewhat steeper, though all are easterly. Upon the assumption that the fault plane is vertical and that the dip of the beds averages 30°, the vertical displacement would approximate 1,500 feet.

Another fault of earlier date affected by the above-mentioned displacement is the one described on page 18 as obliquely cutting out the limestone of the St. Charles formation south of King Creek. This fault is believed to be the same as the one that brings Fish Haven dolomite into contact with undifferentiated Cambrian rocks in the NW. 1/4 sec. 14, T. 7 S., R. 38 E. The fault is regarded as normal, with downthrow to the east. The vertical displacement is not determinable from present data but is probably less than 1,500 feet.

In sec. 35, T. 7 S., R. 38 E., and sec. 2, T. 8 S., R. 38 E., there is a broad depression underlain by Swan Peak quartzite and bounded on the east side by an abrupt ridge composed of eastward-dipping Swan Peak quartzite. The physiographic relations suggest faulting. It is thought that the fault mentioned in the preceding paragraph may extend southward to this locality. This interpretation is therefore tentatively represented on the map.

In the NE. 1/4 sec. 8, T. 8 S., R. 39 E., there is an isolated knoll of eastward-dipping Swan Peak quartzite. Half a mile or more farther west is a group of ledges and knolls composed of eastward-dipping Fish Haven dolomite with Swan Peak quartzite at the west. The strike of the first-mentioned knoll of quartzite is at variance with the strike of the rocks in the knolls farther west. The knolls and ledges are isolated from one another by basalt, so that the relation of the easternmost knoll to the others is concealed. Folding, either open or close, may account for the arrangement seen. If the folding were close the dips would indicate westward inclination of the folds involved, which is unusual in the region. If the folding were open one would expect to find some Fish Haven dolomite accompanying the easternmost quartzite knoll. The dolomite may indeed be present beneath the basalt. On the other hand, the eastward repetition of the Swan Peak quartzite may be explained by normal faulting with downthrow to the west. This is thought to be the more probable explanation, and it is therefore the one selected for representation on the map.

AGE OF THE FOLDING

The folds of the Portneuf quadrangle involve rocks ranging in age from Middle Cambrian to probably Middle or Upper Triassic. Elsewhere in the general region the highest rocks folded to the degree indicated by the geologic structure sections belong to the Wayan formation, of Lower (?) Cretaceous age. The mountain building that produced these folds was therefore later than the deposition of these rocks. It is believed to have been a part of the great mountain-building disturbance which came in the interval between the end of the Cretaceous period and the early part of the Tertiary, generally known as the Laramide revolution.

A subsequent epoch of less intensive disturbance is suggested by the arching of the plane of the Bannock overthrust and by the dips now observed in the Salt Lake formation and some of the associated lavas. These dips are commonly as much as 10° and locally as great as 29°. On the present supposition that the Salt Lake formation is of Pliocene (?) age this second disturbance is presumably to be assigned to the end of the Pliocene.

Some evidence of additional earlier epochs of mountain building is furnished by rocks exposed in quadrangles farther east, but the effects of these earlier disturbances were largely obliterated by the more intensive activity of the Laramide revolution.

AGE OF THE FAULTING

The Bannock overthrust is also ascribed to the Laramide epoch and probably belongs to the later part of that epoch, because it did not occur until the rocks in what is now the upper block had been intensely folded—indeed, folded practically as much as those of the lower block. This is shown in the Montpelier quadrangle, where the folds of both blocks may be observed. The folding of the fault plane, however, is much more open, more in accord with that of the late Pliocene disturbance. It is therefore believed that the folding of the fault plane was much later than the production of the thrust fault itself.

The other thrust faults associated with the folding are believed to have been caused by the Laramide disturbance.

The normal faults differ among themselves in age, some being cut by others. In general they are younger than the Laramide disturbance and hence fall chiefly within the Tertiary period. They were probably produced during the epoch of block faulting that gave rise to much of the so-called "basin and range" structure, of which the Chesterfield Range is here considered an outlying representative. This structure is believed to have been developed in about middle Miocene time.

In addition to these faults there are some in the general region associated with igneous rocks and Tertiary strata that occurred subsequent to the deposition of the Salt Lake formation and hence presumably in early Pleistocene time. To this group probably belongs the fault in the NW. ¼ sec. 6, T. 6 S., R. 39 E., by which the Rex chert on the north is separated from the Salt Lake formation on the south. The Salt Lake formation from exposures in the SW. ¼ sec. 6 is known to overlie the Rex, and its preservation south of the fault line mentioned is believed to be due to downfaulting. As this fault is itself offset by the north-south fault that breaks across the structure in the west half of the section it also may be assigned to the post-Tertiary group. Faults of probably Recent age have been identified in the Montpelier quadrangle. The movements that produced the Pleistocene and Recent faults may have refreshed earlier faults and thus may have given rise to some of the travertine deposits which are conspicuous here and there in the Portneuf quadrangle.

RELATION OF STRUCTURE TO PHOSPHATE BEDS

The folds and faults of the Portneuf quadrangle may be regarded as having been an influential factor in the preservation of the phosphate beds. These beds, which were originally nearly horizontal, might with little doubt have been eroded and to a greater or less extent destroyed in the normal course of weathering and removal of rock débris by the attack of streams. By means of these structural features, however, considerable bodies of phosphate rock have been depressed below the level of erosion and thus preserved for an indefinite period. The presence of the Bannock overthrust, on the other hand, has diminished the amount of this phosphate that might otherwise have been ultimately available.

GEOLOGIC HISTORY

Summary of record.—The latest page of the geologic history of the Portneuf quadrangle, in so far as the record may be deciphered from the evidence at hand, is the geography of the region as it appears to-day. This has been discussed in a preceding section of this report. The business of historical geology is to reconstruct and interpret in orderly sequence the geography of past epochs. With even so great a body of sedimentary rocks as is found in southeastern Idaho the record is very imperfect, for gaps represent the loss of many pages and even of whole chapters and volumes of the story. The total thickness of the strata of southeastern Idaho is about 46,000 feet, or more than 8.7 miles. For the Portneuf quadrangle the record is less complete, all sediments of the Cretaceous and Jurassic periods and some of the later Triassic and earlier Tertiary beds being absent.

Proterozoic era.—No rocks of pre-Cambrian age are exposed in southeastern Idaho, so that inferences regarding the Proterozoic era must be drawn from the evidence furnished by neighboring regions. This evidence suggests that southeastern Idaho, including the Portneuf quadrangle, was land throughout much of that time, but that there was continental deposition, deformation, erosion, and even perhaps glaciation, as in later periods, and that the great continental elements of higher and lower land were already blocked out before the Paleozoic era began.

Paleozoic era.—The Paleozoic record is dominantly marine and thus indicates progressive subsidence of the region. The variations in character of the sediments, however, and the numerous stratigraphic breaks show that there were at times interruptions in subsidence and even reversals of movement, with erosion. These disturbances were gentle, but were fairly well distributed throughout the era. A noteworthy feature is the general dominance of limestone-making processes.

Early in the Cambrian the relatively low and long-eroded surface of southeastern Idaho began to subside and receive sandy sediments, at first probably nonmarine but later marine. The invasion of the sea may not have begun until the later part of Lower Cambrian time or the early part of Middle Cambrian time. The sediments of the Middle Cambrian were chiefly limy, but at the beginning of the Upper Cambrian the sea became more restricted and sands were for a time again the predominant sediments. This condition was succeeded by the renewal of limestone deposition and even more extended invasion of the sea—the first great transcontinental marine inundation of Paleozoic time.

A brief erosion interval with little change in the attitude of the land separates the Upper Cambrian from the Ordovician, when limestone making again took place. A reversal of subsidence in the later part of Lower Ordovician time brought first a change in sedimentation, the deposition of the Swan Peak quartzite, and then an erosion interval that lasted throughout much of Ordovician time. Toward the end of the Ordovician period subsidence with deposition of limestone was resumed.

The Silurian period in southeastern Idaho is represented by a single formation, the Laketown dolomite, reported by Kirk to carry Niagaran fossils. In spite of its apparent conformity with the underlying Ordovician Fish Haven dolomite a stratigraphic break of some magnitude intervenes. The Silurian sea was widespread in the west, but toward the end of the period it withdrew from the region now occupied by the Rocky Mountains, and that entire region became land.

These conditions continued until Middle Devonian time, when the region was again occupied by the sea, and limestone making was resumed without any marked discordance in attitude of the later with the earlier beds. From Middle Devonian through Upper Devonian time the region of deposition was extensively flooded. Gentle earth movements during the period are indicated by changes in the composition and appearance of the beds.

Mild disturbances of the land surface with ensuing erosion are believed to have intervened between the deposition of the Devonian and that of the Carboniferous formations of southeastern Idaho, though the rocks of the two systems lie with little discordance of attitude. There is evidence also of interruption in deposition between the two formations of the Mississippian series, though here again there is no conspicuous discordance of the strata. Limestone forms the main body of the rocks of this series, but shale and sandstone are also present, indicating variations in conditions of deposition. Another crustal disturbance marked the interval between upper Mississippian and Pennsylvanian deposition. The beds of the Pennsylvanian epoch were more sandy than those of the Mississippian epoch, and in all three epochs of the Carboniferous period subsidence of the sea bottom was intermittent or there were minor oscillatory movements. An unconformity separates the Permian from the Pennsylvanian beds. The region receiving deposits was cut off from the sea on the east, south, and west (in part) but had northward and westward connections with the Pacific. Under special conditions of deposition not yet well understood beds of phosphate rock that promise to be of great economic importance were formed, and the overlying strata of the same period include beds of massive chert and flinty shale. The history of the Permian in this region thus constitutes a series of interesting stratigraphic problems.

Mesozoic era.—The change from the Paleozoic to the Mesozoic in southeastern Idaho is marked by strong faunal contrasts rather than by any noteworthy discordance of strata. The Mesozoic is distinguished by alternations on a great scale between marine and nonmarine conditions of deposition. The later part of the era witnessed the accumulation of enormous thicknesses of continental sediments.

Though the North American continent as a whole was a relatively broad land area in the Triassic period, southeastern Idaho was for a time occupied by an arm of the sea connecting with the Pacific at the southwest. In Lower Triassic time open-sea conditions prevailed in southeastern Idaho, but farther east there were shallow marginal seas that dried up at certain seasons and lagoons or estuaries that gave rise to red beds. The shore line of the sea advanced or retreated from time to time, and these movements caused some interfingering of marine and red-bed sediments. At least once during the epoch the sea withdrew sufficiently to permit erosion. After the deposition of the Lower Triassic formations there was widespread erosion, followed by continental deposition, chiefly of the desert type. Of the material then laid down only a small area of Higham grit, in secs. 7 and 18, T. 5 S., R. 40 E., now remains in the Portneuf quadrangle, and no further deposition is recorded there in the exposed formations until the later part of the Tertiary period.

The Jurassic and Cretaceous periods were represented in neighboring areas by thick and extensive formations of both marine and nonmarine types, and there seems every probability that these formations were once represented in the Portneuf quadrangle but that they have been removed by erosion. It is possible that such beds may be concealed in the lower block overridden by the Bannock overthrust, but no direct evidence of them is available. In the Paradise Valley quadrangle they are found emerging from beneath the upper block.

In Jurassic time marine invasions twice alternated with desert continental conditions. The end of the Jurassic was marked by so abrupt a change in the character of the sediments as to suggest mountain building in neighboring areas. The Cretaceous left no record in the immediate region. At its end came the great Laramide revolution, during which the complicated structural features of the region were produced. The great depth of the accumulated sediments and their position are thought to have had a directive influence upon the mountain-building forces.

The interval between the Cretaceous and Tertiary deposition in southeastern Idaho was occupied by erosion, but in neighboring parts of southwestern Wyoming the coal-bearing Evanston formation was laid down in early Tertiary or late Cretaceous time. The nature of this formation suggests that the reduction of the adjacent mountains of Idaho was well advanced by the beginning of the Wasatch Eocene.

Cenozoic era.—The Cenozoic in southeastern Idaho was largely an era of erosion interrupted from time to time by crustal disturbances and by the deposition of continental sediments. No beds of Fort Union age are present and no other Eocene beds are exposed in the Portneuf quadrangle, though beds assigned to the Wasatch formation occur in some of the neighboring quadrangles.

The Miocene was an epoch of erosion. Although it was a time of great volcanic activity in many parts of the West, no such activity is recorded in southeastern Idaho. Crustal disturbances in the middle part of the Miocene are thought to have uplifted the old, worn-down surface, remnants of which in neighboring quadrangles have been called the Snowdrift peneplain, and to have permitted in the later part of the epoch the development of broad and deep valleys. To these disturbances also are attributed the development of the "basin and range" structure of which the Chesterfield Range is an outlying representative.

The erosion of the Miocene may have continued into Pliocene time, but it eventually gave way to the conditions that permitted the Salt Lake formation to accumulate until it blanketed many valleys and some of the lower hills. Some climatic fluctuations during the period are suggested by the nature of the Salt Lake formation. There was also volcanic activity on a considerable scale. Further uplift came toward the end of the Pliocene. According to recent unpublished work by Alden the final activities of the Pliocene were probably erosional and included the development of the Gannett erosion surface.

The Quaternary history of the region is largely one of erosion interrupted by uplift and modified by climatic changes and volcanic outbursts, which have caused the silting up of valleys. The Elk Valley, Dry Fork, and Blackfoot erosion cycles have produced the present topographic features. Late faulting has affected the basalt and even the slopes of hill wash in some parts of the general region and has revived some of the earlier faults. Recent erosion has accomplished little change since the Blackfoot cycle.

MINERAL RESOURCES

No metalliferous deposits are known in the Portneuf quadrangle, and none of commercial value are to be expected, for the rocks exposed are not of the type that is generally favorable for the development of such deposits. It is true that in the foothills of the Portneuf Mountains, especially in the southwestern part of the quadrangle, the sedimentary rocks are of types similar to those in the Bear River Range, west of Bear Lake, in which small pockets of lead and copper ore have been found. These deposits, however, though extensively prospected, have not proved to be commercially valuable.

There are a number of nonmetallic resources that are potentially valuable though not of immediate commercial importance. These are phosphate rock, limestone, basalt, silica (quartzite), and water.

PHOSPHATE ROCK

GENERAL CHARACTER

An extended description of the western phosphate rock, dealing with its texture, appearance, chemical composition, mode of occurrence, origin, and exploitation, has been given in Professional Paper 152, and in the present paper only a brief summary is necessary. Phosphate rock in southeastern Idaho occurs at two horizons, upper Mississippian and Permian, but the Permian beds are the only ones of much commercial importance and the only ones that have been recognized in the Portneuf quadrangle. This rock is characterized chiefly by its oolitic texture (composed of small rounded grains like fish roe) and usual dark color and by its odor (resembling that of crude petroleum) when freshly broken. This odor is not distinctive of phosphate, for many limestones when freshly broken have a similar odor. Weathered material is usually distinguished by a bluish-white coating or bloom that in some specimens has a netlike pattern. The phosphate rock is a bedded deposit of marine origin and must be mined in the same manner as coal.

Phosphate rock is really a mixture or " solid solution " of several phosphatic minerals, but its chemical composition is approximately that of tricalcium phosphate, $Ca_3(PO_4)_2$. Material of this general composition is known under the trade name of " bone phosphate of lime " (abbreviated B. P. L.). There are many accessory constituents, among which vanadium is noteworthy. Some tendency toward enrichment by weathering has been observed. From tests made some years ago in the Geological Survey laboratory the average density of the rock is approximately 2.90, and the weight of a cubic foot of the more massive rock, such as is now being shipped from the mines in this region, is about 180 pounds.

IRON AND ALUMINA CONTENT

Iron and alumina in phosphate rock in excess of 3 to 4.5 per cent in the eastern fields are considered as placing the ore below foreign contract standards. Besides being impurities that increase the quantity of acid necessary for treatment, these substances are supposed to produce, in the present process of superphosphate manufacture, deliquescent salts, which render the drying and shipment of the product difficult. Samples from the western fields that have been tested in the laboratory of the Geological Survey have shown generally less than 1 per cent of either radicle computed in the oxide form. Of the samples thus far analyzed from the Portneuf quadrangle one composite has yielded 4.08 per cent for both taken together. (See p. 84.)

VANADIUM CONTENT

No systematic search for vanadium in western phosphate rock has been made, but Geological Survey chemists have obtained this metal in some analyses, the discovery dating from 1911, when it was found in material from the vicinity of Driggs, Idaho. Samples of phosphate from Montpelier Canyon contained as much as 0.52 per cent of V_2O_5. Three samples from sec. 25, T. 6 S., R. 39 E., in the Portneuf quadrangle, contained 0.17, 0.4, and 0.5 per cent of V_2O_5. Although these quantities seem small in comparison with the content of phosphoric acid usually present in the rock, the vanadium can be precipitated from solutions derived from phosphate rock in making superphosphates, so that the western phosphate rock may be classed as a possible commercial source of vanadium.

DISTRIBUTION OF PHOSPHATE IN PORTNEUF QUADRANGLE

The rocks of the Portneuf Mountains west of Portneuf Valley, within the Portneuf quadrangle, are all older than the Permian. The rocks beneath the basalt and alluvium of Portneuf Valley are also probably pre-Permian, to judge by the exposures along the sides of the valley, but on the supposition of faulting along the east side of the valley, discussed on page 59, it is possible that rocks of Permian age or even younger may be present in the valley. The expense of exploration beneath existing cover practically precludes any search for them there, and their discovery must await the drilling for some other purpose of a well deep enough to penetrate the underlying strata at a favorable locality. The Chesterfield Range, though extensively covered by Tertiary beds, is known to contain folds favorable for the preservation of phosphate beds, and phosphate rock is actually exposed in four bands of differing extent in connection with these folds. Phosphate rock is also present at accessible depths in the Blackfoot Mountains, in the northeastern part of the quadrangle. The details of distribution, together with data on the character and quantity of phosphate present, are given in the descriptions of the several townships that follow.

DESCRIPTION OF TOWNSHIPS THAT CONTAIN PHOSPHATE

T. 5 S., R. 38 E.

A detailed description of T. 5 S., R. 38 E., is given in the writer's account of the Fort Hall Indian Reservation [44] and need not be repeated here. The southeastern part of the township is included in the Portneuf quadrangle. Much of the area so included is covered with Tertiary and Quaternary sediments, but phosphate beds are exposed in sec. 36 and vicinity.

Field work in 1923.—The field work of 1923 necessitated a few changes in the earlier mapping, but these do not seriously affect the published interpretations. Much of the area here mapped as Salt Lake formation was mapped in the earlier report as Tertiary or Quaternary. (See p. 51.) A slight change in the mapping of the phosphate beds in the SE. ¼ sec. 36 has also been made necessary by work in the adjacent townships. The phosphate-bearing syncline is not closed off at the south, as tentatively mapped in the previous report, but continues southeastward into T. 6 S., R. 39 E. There is also some hitherto unsuspected minor folding, involving phosphate beds, on the south side of Rock Creek in the southeast corner of the township. The principal phosphate-bearing fold in the township is the Rock Creek syncline, described on page 53. It is probably to be regarded as a synclinorium, rather than a simple syncline, so that its structure is somewhat more complex than was formerly supposed.

[44] U. S. Geol. Survey Bull. 713, pp. 39, 40, 99–103, 1920.

Results of previous prospecting.—In 1913 the Geological Survey party prospected the phosphate in sec. 36 of this township by means of a trench and six test pits. The trench, which began with the lower limestone bed of the Phosphoria formation, was 68 feet long, from 2½ to 4 feet deep, 2½ feet wide, and at right angles to the strike of the beds. The strike of the lower limestone bed was N. 89° W., and the dip 20° N. The pits, which were dug in the line of continuation of the strike of the trench across the phosphatic shale and ranged in depth from 2½ to 4½ feet, were spaced at the following intervals: No. 1, 40 feet north of the end of the trench; No. 2, 15 feet north of No. 1; No. 3, 25 feet north of No. 2; No. 4, 45 feet north of No. 3; No. 5, 20 feet north of No. 4; No. 6, 135 feet north of No. 5. The hill slope above was all strewn with float of Rex chert. The results follow:

Partial section of phosphate shales in NE. ¼ SE. ¼ sec. 36, T. 5 S., R. 38 E., compiled from trench and six test pits

Character of beds	P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
	Per cent	*Per cent*	*Ft.*	*in.*
Soil and other material.				
Shale, broken pieces, black to brown, somewhat phosphatic; contains small lenses and scattered oolites			2±	
Not exposed			48	
Soil and other material			1	
Shale, brown			1	
Not exposed			7	
Soil that contains fragments of cherty limestone and shale			18±	
Phosphate rock layer, black, medium oolitic				1
Shale, black				7
Not exposed			16	
Limestone, deep drab				3
Shale, brown, with scattered oolites				3
Phosphate rock, black, medium oolitic				2
Shale, brown; base not shown			1	
Not exposed			10	
Phosphate rock, black, finely oolitic	31.40	68.7	1	9
Shale, brown				6
Not exposed			10	
Shale, black, phosphatic			1	
Not exposed			15	
Limestone, scattered oolites				3
Shale, black, weathered brown			2	11
Limestone, black, fetid, fossiliferous; "cap lime"			2	1
Main bed of phosphate rock, oolitic	33.02	72.1	2	1
	35.46	77.4	2	
	33.14	74.1	2	
Phosphate rock, sandy				6
Zone, weathered, yellow, sandy				9
Phosphate rock, hard, dense				3
Limestone, lower Phosphoria, fossiliferous.				
			146	5

The phosphate beds near the northwest corner of sec. 18, in sec. 13 of the adjoining township, were also sampled by the Geological Survey party in 1913. The prospecting trench was about 30 feet long and from 3½ to 5½ feet deep, and its strike was N. 19° E. The strike of the phosphate beds was N. 46° W., and the dip 82° SW. The results of this work are also given for comparison.

Partial section of phosphate shale about 20 feet west of section corner of NE. ¼ NE. ¼ sec. 13, T. 5 S., R. 37 E.

Character of beds	P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
	Per cent	Per cent	Ft. in.
Shale, brown to light, sandy, broken, top not exposed.			
Phosphate rock, black, fine grained, hard, cherty (?)			1 3
Broken zone, shale and phosphate rock, brown to black			1 8
Phosphate rock, dark brown, finely oolitic, somewhat shaly, much broken, with interbedded shale			2 8
Shale, phosphatic, black to brown, with a few narrow bands of phosphate, much broken			4 9
Broken zone, mingled phosphate rock and shale, brown to yellowish			1 3
Phosphate rock, fine to coarse oolitic texture, beds up to 3 inches thick, dark gray to black, weathering yellowish, and in broken blocks coated white, including—			
Inches			
Sample 5 22	34.65	75.71	5 6
Sample 4 22	34.59	75.57	
Sample 3 22	32.64	71.31	
Phosphate rock, medium oolitic, brownish gray, with a few yellow sandy streaks; beds have a maximum thickness of 1½ inches, grading into thin shaly phosphate (sample 2)	23.98	52.31	1 5
Shale, yellowish brown, finely banded, iron stained, much broken and containing scattered phosphate nodules and streaks			2 6
Chert, with phosphatic nodules and fragments of discinoids, much broken			10
Shale, yellowish brown, sandy, with irregular phosphate streaks			3
Phosphate rock, medium to fine, oolitic; contains yellow sandy streaks (sample 1)	22.97	50.18	1 5
Sandy beds, yellowish brown, scattered phosphate nodules, banded chert, black, broken; base not seen			6
			26 9

Phosphate deposits.—The summary for this township given in the earlier report cited is applicable here and with minor corrections is repeated for reference.

A thick bed of high-grade phosphate rock has been found and sampled in secs. 18 and 36. The outcrop of the phosphate shales in secs. 17 and 18 is alined well with that in sec. 36. [Later work suggests that both are parts of the Rock Creek syncline.] Postphosphate rocks lie on the northeast side of this line. These facts suggest that much of the northeastern part of the township may be underlain by valuable phosphate rock within workable limits. However, the extensive cover and the complex structure of the exposed parts of the older sedimentary rocks make it unwise to estimate the phosphate resources of the covered area except of those parts relatively near the exposed areas. It is estimated that about 8,120 acres are underlain by available phosphate rock. The complexly faulted small areas of Rex chert in secs. 28, 29, 32, and 33 are not included in this estimate.

About 250 acres included in the above figures lies east of the reservation boundary in secs. 25 and 36.

In the prospect made by the survey party just over the township line from the northwest corner of sec. 18 the phosphate bed was found to have a thickness of 66 inches and an average content of 33.96 per cent phosphorus pentoxide (P_2O_5) equivalent to 74.19 per cent tricalcium phosphate ($Ca_3(PO_4)_2$). In the NE. ¼ SE. ¼ sec. 36 in this township the prospect made by the survey party showed the phosphate bed to be 73 inches thick with an average content of 34.37 per cent phosphorus pentoxide, equivalent to 74.5 per cent tricalcium phosphate. The weight of such rock from previous determination is about 180 pounds per cubic foot. On the assumption that the lower thickness is the average for the area, it is estimated that this township contains as a minimum

148,008,900 long tons of high-grade phosphate rock, at a depth of 5,000 feet or less. The estimate assumes that the rocks are horizontal. The rocks are, however, inclined at different angles, so that the estimate should fall somewhat below the actual content of the phosphate beds. In view of the complex structure of the township it seems wise to leave this difference as an additional margin of safety for the estimate given.

The small areas of phosphate in the SE. ¼ SE. ¼ sec. 36 were not included in the above estimate and would tend slightly to increase it. On the other hand, it now seems reasonably certain that the Bannock overthrust or a closely related thrust fault underlies this township. Its presence may adversely affect the phosphate content of the Rock Creek syncline, thus tending to reduce the estimate. As from existing data there is no other than an arbitrary basis for revising the estimate, it is believed better to let the figures stand as given. The areas in this township officially classified as phosphate land are shown in Figure 3.

T. 6 S., R. 38 E.

The two northern tiers of sections in T. 6 S., R. 38 E., were described in the Fort Hall report, previously cited. The Portneuf quadrangle includes most of the eastern half of the township. The only exposures of older rock within the area here mapped are the Cambrian beds north and south of the mouth of Topons Canyon and the Carboniferous beds in the northeastern part. The rest of the area is occupied by Tertiary and Quaternary sediments and by Portneuf Reservoir. West of Portneuf River and Portneuf Reservoir the pre-Tertiary rocks are of Cambrian and Ordovician age. Between these and the Carboniferous rocks on the east there is believed to be a normal fault. (See pp. 59 and 60.)

Phosphate deposits.—The phosphate beds in sec. 1 were not recognized in the more cursory mapping of 1913 but were followed out in some detail in 1923. The area there underlain by phosphate is estimated at approximately 80 acres. No prospecting of the phosphate beds in this township was attempted, but assuming the thickness of the main phosphate bed to be 6 feet, as indicated in the prospect in sec. 36, T. 5 S., R. 38 E. (the adjoining township), and estimating in the same way as before, we find that the 80 acres would contain about 1,845,000 long tons of high-grade phosphate rock. The computation is made on the assumption that the beds are horizontal, whereas they are inclined, so that the actual quantity present might be greater than the figure given. On the other hand, the phosphate-bearing area (see fig. 3) is in part concealed by Tertiary beds and is traversed by at least two faults, which may cut out part of the phosphate. The figure given is, therefore, conservative and reasonable. None of this phosphate is deeper than a few hundred feet.

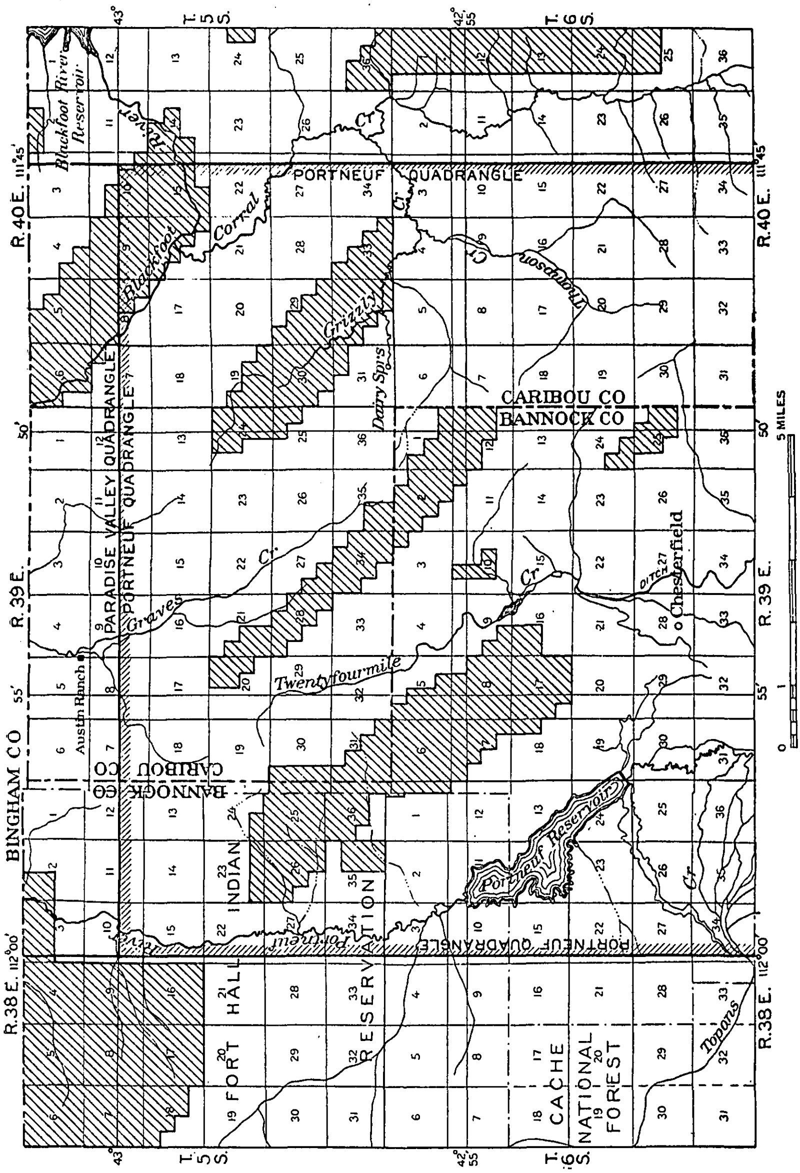

FIGURE 3.—Map showing areas of classified phosphate land in townships included wholly or in part in the Portneuf quadrangle

T. 5 S., R. 39 E.

More than half of T. 5 S., R. 39 E., including a strip 1½ miles wide in the Paradise Valley quadrangle, is occupied by Tertiary and Quaternary sediments with associated igneous rocks, which completely conceal the pre-Tertiary formations. These earlier rocks crop out southeast of an irregular line that extends northeastward from the NW. ¼ sec. 30 to the NE. ¼ sec. 24.

The township lies mostly in the interior of the Chesterfield Range, though it extends down to Blackfoot Valley at the north and northeast. It is entered in secs. 1, 5, and 6 by the road from Blackfoot Dam to Ross Fork, one of the few thoroughfares of the region and locally a good automobile road. There are two other roads, both of which are very poor and in places practically impassable for automobiles. One of these connects the town of Chesterfield with the Austin ranch and Ross Fork road by way of Twentyfourmile and Warbonnet Creeks, and the other connects both Chesterfield and Corral Creek with Blackfoot Valley by way of Grizzly and lower Graves Creeks.

Structural details.—The township is crossed by or contains parts of all the major folds of the Chesterfield Range, though such parts of the Nigger Creek syncline as may be present are concealed by Tertiary and Quaternary rocks. The general structural relations are shown by the geologic structure section A–B, Plate 2.

On the basis of the available exposures the lowest beds of the Grizzly Creek anticline brought to the erosion surface, upon which the Tertiary and Quaternary beds lie, are identified as the Ross Fork limestone. The space available for the folded Ross Fork beds is apparently too narrow to accommodate them without some break. It is therefore believed that the fault recognized on Grizzly Creek in T. 5 S., R. 40 E., continues into T. 5 S., R. 39 E., but with diminished throw.

The highest beds in the Graves Creek syncline are Portneuf limestone. The phosphate beds, if present in normal sequence, would therefore lie very deep in the trough portions of this fold. The lower part of this syncline has doubtless been cut off by the Bannock overthrust and phosphate is probably absent from the area occupied by it, except along its west flank, where it merges with the adjacent anticline.

Beds of Brazer limestone occupy the core or central area of the Twentyfourmile anticline. The Bannock overthrust probably cuts out much of this fold, and to judge from exposures farther south its fault plane is thought to approach relatively near the surface along the crest of the fold. Exposures of cherty breccia along the same general line suggest the cracking through or faulting of the upper block, as indicated in the map and section. Phosphate beds are exposed along both limbs of the anticline.

The Rock Creek syncline is shallow and affects only the southwest corner of the township, secs. 30 and 31. The syncline is actually a synclinorium consisting of two roughly parallel shallow synclines separated by a low anticline, broken and modified by minor folds. The transverse anticline shown on the map is apparently a local upwarping of the synclinorium, which makes it narrower by bringing the phosphate beds on opposite sides closer together. The cross fold dies out rapidly eastward, for the boundary between the Wells and Brazer formations is only slightly if at all affected by it. The east side of the synclinorium is broken by two faults, which cause the beds on the west to be lowered with respect to those on the east and are therefore presumed to be normal. The older of the two where it crosses the canyon has a westerly dip of about 30° and is more gently inclined than the younger fault, against which it terminates at the north.

Phosphate deposits.—The Phosphoria formation, dipping about 50° W., enters the SW. ¼ sec. 35 and extends northwestward to the SW. ¼ sec. 21, where it passes beneath Tertiary cover, thus forming a belt roughly 3½ miles long. On the basis of the postulated structure, as shown in section A–B (pl. 2), the belt underlain by phosphate would be about 800 feet wide, but it broadens southward so that at the line C–D it may be more than half a mile wide.

A second area underlain by the Phosphoria formation occupies parts of secs. 30 and 31. In sec. 30 the Rex chert is downfaulted against the Wells formation on the east, and the phosphate beds are not exposed, but lower beds of the Woodside just overlap the township line. All three formations pass beneath cover in the northern half of the section. In sec. 31 the phosphatic shale member is exposed in contact with the Wells on both sides of the syncline, but the beds along the east side are much broken and sheared and vary in thickness in such manner as to indicate slight faulting. On the west side they are likewise interrupted by a fault that breaks across two minor folds and slightly offsets the phosphatic shale. A subordinate syncline on the township line near the southwest corner contains some of the phosphatic shales for a distance of about a quarter of a mile, but the size of this area as mapped may be somewhat exaggerated.

No prospecting in this township was done by the Geological Survey party, but two prospects in sec. 31 were visited. One in the NE. ¼ SW. ¼ by the roadside in the canyon bottom on the ranch of F. L. Corneilison, is a hole about 25 feet deep in a nearly vertical zone of crushed phosphatic shale, from which some very large nodules of impure limestone have been taken. One of these nodules, an egg-shaped mass 3½ feet long, 18 inches wide, and 18 inches high, lay on the dump. At the mouth of the pit about 5 feet of finely oolitic phosphate in shattered beds was exposed. A rough sample comprising the upper 18 inches was taken and later analyzed at the laboratory of the Geological Survey. It proved to be very poor, containing only 13.27 per cent P_2O_5, equivalent to 29.83 per cent $Ca_3(PO_4)_2$. The material was too dirty to provide a satisfactory sample. The other prospect was on a low point above Corneilison's ranch, in the NW. ¼ SE. ¼ of the section. It was a caved pit near the contact of the Rex chert with the phosphatic shale. Some hard lumps of phosphate rock were lying on the dump, but no samples were taken.

In 1913 the Geological Survey party prospected the phosphatic shale in the NE. ¼ SE. ¼ sec. 36 of the adjacent township, T. 5 S., R. 38 E., by means of a trench and six pits. The results of this prospecting, tabulated on page 70, may be regarded as showing in detail the general character of the phosphatic shales in the southwestern part of T. 5 S., R. 39 E.

The phosphate band extending from sec. 35 to sec. 21 was not prospected, but float fragments collected from two localities in the SE. ¼ SW. ¼ sec. 35 and the SE. ¼ NE. ¼ sec. 34 yielded 37.10 and 36.87 per cent P_2O_5, equivalent to 81 and 79.10 per cent $Ca_3(PO_4)_2$, respectively. These samples, which may have been somewhat enriched by weathering, show nevertheless that high-grade phosphate is present.

The Geological Survey prospect in sec. 36, T. 5 S., R. 38 E., showed the presence of a phosphate bed 73 inches thick with an average content of 34.37 per cent of phosphorus pentoxide, equivalent to 74.5 per cent tricalcium phosphate. A similar group of prospects made by the Geological Survey in 1916 in the SE. ¼ NE. ¼ sec. 30, T. 5 S., R. 40 E., indicated the presence of a phosphate bed that for the purposes of computation could be assumed to have a thickness of at least 5 feet and a phosphate content greater than 70 per cent of tricalcium phosphate. (See p. 84.) Previous work in the Idaho phosphate field has shown that the phosphate rock has a tendency to preserve its thickness and quality over wide areas. It seems reasonable to believe, therefore, that T. 5 S., R. 39 E., which lies between the two prospects mentioned, should contain rock of thickness and quality corresponding with that at the localities cited. For purposes of computation it is therefore assumed that the principal phosphate bed in this township is at least 5½ feet thick and that it contains at least 70 per cent of tricalcium phosphate. The depth limit for such a bed under current regulations of the Geological Survey regarding land classification [45] is 4,500 feet. From structure sections A–B and C–D (pl. 2) it appears that all the phosphate present in the area not concealed by Tertiary and later rocks lies within 3,000 feet of the surface and therefore well within the depth limit assigned.

[45] Smith, G. O., and others, Classification of the public lands: U. S. Geol. Survey Bull. 537, pp. 129–132, 1913.

It would be possible with a fair degree of assurance to project the phosphate bed exposed in the SW. ¼ sec. 21 northwestward along its strike beneath cover through the NW. ¼ sec. 7. There are, however, uncertainties of structure inherent in the general structural complexity of the region, especially in relation to the possible existence of the overthrust fault block to which the Cambrian beds in sec. 18 may belong (see p. 56), that render this action inadvisable. Because of these uncertainties and of the relative abundance of phosphate rock in this field the areas here regarded for purposes of classification as phosphate land are restricted rather closely to the sections in which the phosphate-bearing folds are actually exposed. On this basis it is estimated that T. 5 S., R. 39 E., contains about 1,400 acres underlain by accessible phosphate. The area withdrawn, as shown in Figure 3, is somewhat larger than this because the borders of the withdrawn lands do not follow the outcrop or structure lines of the phosphate bed but necessarily conform with the legal subdivisions, the smallest of which is 40 acres. On the assumption, as in previous computations, that a cubic foot of phosphate weighs 180 pounds, the 1,400 acres would contain about 26,953,000 long tons of phosphate rock if the bed were horizontal. The fact that the beds dip at various angles would tend to increase this estimate, but the presence of minor faults, folds, and crushed zones, such as are known to occur in at least part of the area, would tend to offset this increase. It is therefore thought that the estimate given is reasonable.

T. 6 S., R. 39 E.

T. 6 S., R. 39 E., the central township of the quadrangle, extends from Portneuf Valley at the southwest through the foothills to the highest ridge of the Chesterfield Range at the northeast. It contains the town of Chesterfield, the largest settlement in the Portneuf quadrangle, which is connected by good roads with other parts of Portneuf Valley and with Bancroft and other shipping points on the Oregon Short Line Railroad, 8 to 10 miles to the south. Poor roads across the range pass northward and northeastward from Chesterfield.

Pre-Tertiary rocks are exposed only in the northeastern, northwestern, and southeastern parts of the township. Nearly three-quarters of the township is occupied by Tertiary and Quaternary rocks.

Structural details.—The Graves Creek syncline is represented by part of its western limb. The Twentyfourmile anticline and the Rock Creek syncline also cross the township. The general character of these folds is displayed in sections C–D and A–B, Plate 2. The plane of the Bannock overthrust is brought to the surface in sec. 10 by the arching and erosion of the thrust plane. (See p. 53.)

The highest beds of the Graves Creek syncline, which crop out a few hundred feet northeast of sec. 1, are Portneuf limestone. The phosphate beds, even if present in normal position, would therefore lie too deep in the central portions of this fold to be considered accessible. There is great probability that they are cut out by the Bannock overthrust. They are present, however, along the southwest limb of the syncline where it merges with the Twentyfourmile anticline.

The core of the Twentyfourmile anticline consists of Brazer limestone with a subordinate mass of Rex chert (presumably belonging to the lower fault block) exposed in the midst of it. The southwest limb of the fold is largely concealed, but it is believed to contain the Phosphoria formation in normal order.

For reasons stated on page 54 the Rock Creek syncline is thought to be relatively shallow and to contain two subordinate synclines. The west limb of the fold, which is partly exposed northwestward from sec. 18, is broken by a fault, supposedly a thrust, that locally cuts out the phosphatic shale. In sec. 6 this fault participates with other faults and minor folds in producing a highly complex structure. The phosphatic shale and upper beds of the Wells are there arched in a small anticline extending northwestward from the SW. 1/4 SE. 1/4. This anticline is broken down on the southwest limb by a supposedly normal fault that introduces at the west a fragmentary, transverse syncline containing some beds as high as the lower part of the Woodside. Farther northwest this fault brings beds of the Salt Lake at the south into contact with Rex chert at the north. Both the folds and the fault just described are again cut by a normal fault with downthrow to the west. This is apparently the youngest fault in the group. Probably none of the faults have a throw greater than a few hundred feet.

In the SE. 1/4 sec. 25 the phosphate beds are partly cut out by a minor fault believed to be a thrust.

Phosphate deposits.—A belt of phosphate rock extends northwestward through parts of secs. 1, 2, and 12. The phosphate rock is here overturned and dips southwestward beneath older rocks. It doubtless underlies the Rex area in sec. 10, if the interpretation above suggested for this area is correct. It also enters sec. 6 from the northwest and extends southeastward beneath cover an unknown distance but with little doubt crossing the entire township and including the exposures in secs. 24 and 25. According to present data the Rock Creek syncline narrows greatly southeastward, so that the phosphatic shale may be absent in some parts of the fold.

No prospecting was done by the Geological Survey party in sec. 6, but the character of the phosphate in that area, where not too much broken and infiltered with dirt, is doubtless represented by the results obtained by prospecting in sec. 36, T. 5 S., R. 38 E., to which reference has already been made.

In 1923 the Geological Survey party made two prospects in the NW. ¼ sec. 17 and the NE. ¼ sec. 18, near the section line. By means of horses, plow, and scraper a trench across the general strike of the beds, about 100 feet long, 4½ feet wide, and 5 feet deep, was made at the first-named locality. From float at the surface this seemed a favorable place. The overburden proved very thick. Some reddish-weathering brown shale or impure limestone and some whitish and yellowish weathering rock appeared in the bottom of the cut, but none of the dark and black phosphate usually seen. At the southwest end of the trench some pieces of gray-weathering hard phosphate, apparently representing a thin bed near the base of the section, were encountered early in the plowing, but the bed itself was not exposed. The results here were so unpromising that further work was abandoned, and a new trench, the second above mentioned, was started at a neighboring locality. This trench was 30 feet long, 4 feet deep, and 5 feet wide. The overburden was 2 feet or more thick. No bedrock was exposed except some decomposed, yellowish-weathering, impure limestone. At the place where phosphate should normally occur, near the top of the underlying Wells formation, there was an earthy jumble of phosphatic sand and fragments of phosphate rock with red clay. This was deepened 2 or 3 feet with pick and shovel, but no solid rock or change of material was noted. Float of hard rock lay on the surface next to the exposed upper beds of the Wells at this locality, as in the other trench, and some material of this character appeared in the cut, but no bed of it was exposed. A random sample of float fragments was taken for analysis. This proved to be low-grade material containing only 25.63 per cent of phosphorus pentoxide, equivalent to 55.95 per cent of tricalcium phosphate.

The phosphate bed in secs. 1 and 2 was not prospected, but in 1923 the Geological Survey party dug a trench in the phosphatic shale in the SE. ¼ NW. ¼ sec. 25. The upper beds of the Wells formation here strike about N. 42° W. and dip about 18° NE. The trench, which was nearly at right angles to the strike of the rocks, was 30 feet long, 2 feet wide, and 4 feet 8 inches deep at the deepest place. The results of the prospecting are tabulated below. All the phosphate rock exposed was very dirty.

Section of phosphate beds in the SE. ¼ NW. ¼ sec. 25, T. 6 S., R. 39 E., Portneuf quadrangle, Idaho

Locality No.	Character of material	P_2O_5	$Ca_3(PO_4)_2$	Thickness
M-92-23	Not exposed.	*Per cent*	*Per cent*	*Ft. in.*
	Phosphate rock, grayish brown, medium oolitic, beds 1/16 to ½ inch thick; includes limestone nodule 6 inches thick:			
	Sample 3, hand-picked material across the part of the section represented by sample 1	31.98	69.80	
	Sample 2, upper 2 feet 4 inches	30.09	65.68	2 4
	Sample 1, lower 2 feet	31.07	67.80	2
	Shale, brown			4
	Limestone, upper part of Wells			
				4 8

The pieces taken for sample 3 were selected so as to be as free as possible from dirt. The part of the section represented by sample 2 was too dirty to make hand sorting worth while. As it proved, the hand-sorted material was only slightly richer than the unsorted sample. Alumina and iron are low in the three samples, ranging from 0.68 per cent in sample 3 (selected material) to 0.92 per cent in sample 1. Chromic oxide, Cr_2O_3, is present in all three samples, but in little more than traces. Vanadium calculated as pentoxide (V_2O_5) is present in all samples. (See p. 68.) Fluorine is present in amounts less than 0.04 per cent.

In view of the results of prospecting in sec. 36, T. 5 S., R. 38 E., and sec. 30, T. 5 S., R. 40 E., above cited, together with those just given, it seems fair to assume for this township the presence of a 5-foot bed of phosphate of at least 70 per cent grade. The depth limit for such a bed under current regulations is 4,000 feet.

Although the phosphate is believed to be continuous throughout the Rock Creek syncline, the abundant cover and the uncertainties regarding concealed structure render it inadvisable to apply the tonnage computation to areas much to the southeast of the line C–D. (See pl. 1.) The phosphate-bearing area, which is bounded approximately by the Wells formation on the southwest and by the 6,000-foot structure contour on the northeast, is therefore arbitrarily cut off about half a mile southeast of the Rex exposure in the SE. ¼ sec. 18. Similarly the phosphate-bearing area in secs. 24 and 25 is cut off at the section and township lines respectively. The Rex area in sec. 10 is thought to indicate the presence of accessible phosphate rock in the lower thrust block of the Bannock overthrust. In secs. 1–3 and 12 the southwest limit of the phosphate-bearing area, assumed for purposes of computation, is the projected line along which the phosphate as shown in structure section C–D is cut off at depth. The northeastern limit would normally be the contact of the phosphatic shale with the Rex, but as an additional margin of safety the Rex and Woodside contact is taken instead. The areas thus delimited taken together contain about 3,300 acres. As the withdrawn lands must follow the boundaries of legal subdivisions their acreage as shown in Figure 3 is somewhat larger.

If the weight of a cubic foot of phosphate rock is assumed as before to be 180 pounds, 3,300 acres underlain by a 5-foot bed would contain approximately 57,756,000 long tons of phosphate rock if the strata were horizontal. Allowance for the dip would increase this figure, but complexities of structure, with consequent shattering or injury to the phosphate rock, would tend to offset this increase. The estimate as given is therefore considered reasonable.

T. 5 S., R. 40 E.

T. 5 S., R. 40 E., lies mostly in the Portneuf quadrangle but includes strips a mile or more wide in the Paradise Valley, Cranes Flat, and Henry quadrangles. It contains parts of the Blackfoot Mountains, Reservoir Mountain, the Blackfoot lava field, and the Chesterfield Range. Blackfoot River, which leaves the reservoir of the same name in sec. 12, makes a broad loop westward through the northern part of the township. Railroad facilities are 25 miles or more away, but fair roads connect the township with Soda Springs, Blackfoot, and Fort Hall, which are the chief available shipping points.

Structural details.—The principal structural features of the township comprise parts of six large folds. One of these, entirely outside the Portneuf quadrangle, is an anticline mostly exposed in the Cranes Flat and Paradise Valley quadrangles but occupying parts of secs. 1 and 2 of this township. The west limb is faulted, but the lower member of the Phosphoria is preserved along the fault, making available the fine section described below from sec. 34 of the adjoining township. A second fold, which also lies completely outside the Portneuf quadrangle, occupies secs. 1, 2, 11, and 12 and is thought to be the continuation of the Reservoir syncline of the Henry quadrangle. The Thaynes and Woodside beds in secs. 24, 25, and 36 are also probably parts of the same fold. It consists mainly of beds of the Thaynes group, including some beds of the Portneuf limestone. Much of this fold is concealed by basalt, and it is thought to be offset beneath cover by the Little Gray fault. (See p. 59.) The lower part of it is probably cut off by the Bannock overthrust. The other folds, named in order southwestward, are the Corral Creek anticline, the Nigger Creek syncline, the Grizzly Creek anticline, and the Graves Creek syncline. These folds are described under their respective names on pages 48 to 53. (See also pl. 8.)

Phosphate deposits.—A small area of phosphate-bearing shale occurs in the NW. ¼ NE. ¼ and the NE. ¼ NW. ¼ sec. 2, just inside the township line, where the first anticline mentioned in the preceding paragraph is faulted against the adjacent syncline. The phosphate here terminates against the fault and is probably confined to the area designated. The syncline just mentioned is so deep that any phosphate it might otherwise contain is probably cut out by the Bannock overthrust.

The Corral Creek anticline contains a considerable body of phosphate most readily accessible along its crest. The area containing this phosphate is about 1¼ miles wide in secs. 14, 15, and 16 and extends northwestward 4 miles to the northwest corner of the township, where it is about a mile wide. This phosphate-bearing area may extend southeastward from secs. 14–16 with the same general trend, but a thick cover of basalt overlies that portion of the area and renders any phosphate that it may contain practically inaccessible.

The Grizzly Creek anticline contains phosphate in at least the upper portions of the fold. The area affected is approximately three-quarters of a mile wide and extends northwestward about 3½ miles from the township line in secs. 32 and 33.

Before 1916 no prospecting for phosphate had been done in this township. In that year the Geological Survey party prospected and sampled the phosphatic shale on the crest of the knoll in the SE. ¼ NE. ¼ sec. 30. The Wells in prominent ledges forms the west edge of the crest and the west slope of the hill. The phosphatic shale occupies the sag and furnishes an abundance of excellent float. The Rex forms the eastern part of the hill.

The overburden proved to be 2 feet or more thick, and below it a much weathered biotite-hornblende andesite was encountered in a gently inclined dike, which cut out much of the phosphatic shale, leaving an eastward-pointing wedge of this rock between the westward-dipping andesite and the nearly vertical beds of the upper part of the Wells. The phosphatic shale in this wedge had the structure of a syncline overturned eastward. This structure, however, is local, for the distribution of the shale as mapped shows that it forms a steeply inclined stratum with dips ranging on both sides of the vertical, depending upon the relative position of the stratum measured with regard to the fold in which it appears to be involved.

Four trenches were dug. No. 1, at the base of the section, was 26½ feet long, 2½ feet wide, and 5½ feet in maximum depth, with a strike N. 53° E. No. 2, which was in line with No. 1 but 6 feet from it, was 8 feet long, 2½ feet wide, and 3¼ feet deep. No. 3 was offset 31 feet north of No. 2 but was so placed as to continue the phosphate section upward. It was 40 feet long, 2¼ feet wide, and 4½ feet in maximum depth, with a strike N. 46° E. No. 4 was offset about 100 feet N. 83° E. from No. 3. It was about 6 feet long, 2 feet wide, and 2 feet deep, and 165 feet N. 56° E. from the top of the Wells as exposed in No. 1. The lithologic details observed in the four trenches and the chemical determinations made from the samples collected in them are given below.

Partial section of phosphatic shales exposed in four trenches in SE. ¼ NE. ¼ sec. 30, T. 5 S., R. 40 E., Idaho

Trench No. 4

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	*Per cent*	*Ft.*	*in.*
M-136-16	Limestone, brown, with phosphatic streaks, top not exposed				10
	Phosphate rock, thin bedded, coarsely oolitic, with shaly streaks, brownish gray				6
	Shale, phosphatic, brown, somewhat oolitic				6
Sample 7	Phosphate rock, dense, siliceous, black; one bed	24.95	54.5		2
	Shale, phosphatic, brown				3½
	Phosphate rock, coarsely oolitic, gray to black, layers ¼ to 1½ inches thick				8
	Limestone, brownish gray, with oolitic grains; one bed				3
	Shale, phosphatic, calcareous				8
	Limestone, brown, somewhat shaly; base not exposed				8

Trench No. 3

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
	Soil and overburden, not measured.				
	Limestone, brown, not well exposed, about			2	6
	Phosphate rock, much broken, mingled with soil, some pieces coarsely oolitic, black, about			3	
Samples 6 and 5.	Phosphate rock, brownish gray, thin bedded, finely oolitic, part shaly, some coarsely oolitic layers, occasional calcareous nodules; 2 samples, 2 feet each	22.27 18.21	48.6 39.3	4	
	Limestone, brown, weathering black, massively bedded			1	9
Sample 4	Phosphate rock, gray to black, thin-bedded, finely oolitic, with some shaly material weathering reddish black or gray	31.40	68.6	2	1
	Weathered zone with brownish soil. Fragments of phosphate rock, shale, and brown limestone			1	9
	Phosphate rock, thin bedded, dark gray, with shaly streaks, finely oolitic				5
	Phosphate rock, thin bedded, finely oolitic, with shaly streaks and calcareous layers; much weathered and broken			1	10
	Soil zone, brown, powdery, with pieces of phosphate rock and limestone				10
	Phosphate rock, grayish brown, thin bedded, finely oolitic, with calcareous beds				9
	Limestone, brown, with phosphatic streaks, much broken			1	3
	Soil zone, brownish gray, powdery, with fragments of brown limestone and phosphatic shale			2	
	Phosphate rock, brownish gray, shaly, with nodules of limestone, finely oolitic, mingled with earth, about			1	9
	Limestone, brown, shaly, with streaks of phosphate rock, much broken			1	4
	Phosphate rock, brownish gray, shaly, finely oolitic, much broken			1	6
	Phosphate rock, very shaly, much broken, mingled with soil, apparently in syncline			1	3
	Soil zone, brown				6
	Limestone, brown, impure				3
	Phosphate rock, brownish gray, shaly, finely oolitic, much broken				7
	Limestone, brown, shaly, thin calcite veins				6

Trench No. 2

[Only overburden and decomposed andesite exposed; no measurements.]

Partial section of phosphatic shales exposed in four trenches in SE. ¼ NE. ¼ sec. 30, T. 5 S., R. 40 E., Idaho—Continued

Trench No. 1

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
		Per cent	*Per cent*	*Ft. in.*
	Andesite, weathered into yellowish gravel, to depth of at least 2 feet below overburden.			
Sample 3	Phosphate rock, brownish gray, thin bedded, medium oolitic, much brecciated Phosphate rock, dark gray, hard, dense, finely oolitic, single bed Phosphate rock, brownish gray, thin bedded, medium oolitic	32.87	71.7	1 4½ 7½
Sample 2	Phosphate rock, brownish gray, coarse to medium oolitic, beds 1/16 to 1½ inches thick, possibly in part equivalent to those below	32.53	71.0	2
Sample 1	Phosphate rock, brownish gray, coarse to medium oolitic, beds ⅛ to 1½ inches thick, somewhat folded	31.33	70.5	1 4
	Shatter zone, soil with fragments of limestone and phosphatic material			1 3
	Limestone, top of Wells formation.			

The distance across the outcrop of the phosphatic shale is about 170 feet. In spite of the generally steep dip this is probably somewhat greater than the actual thickness of the shale member, because of the disturbances above noted. In the trenches described a thickness of about 41 feet of strata was measured. Of this thickness 24 feet 7 inches was phosphate rock, some of it possibly duplicated and nearly half of it too broken or dirty for sampling. The 13½ feet sampled averaged about 60 per cent tricalcium phosphate. Near the base a bed 5 feet 4 inches thick with possibly some duplication averaged 71.1 per cent tricalcium phosphate.

The iron and alumina content of the phosphate sampled appears to be within the prescribed limit (p. 68). A composite of samples 2 and 3 yielded 1.48 per cent of iron and alumina together. A composite of the somewhat poorer samples 5 and 6 yielded 1.04 per cent Fe_2O_3 and 3.04 per cent Al_2O_3.

In 1916 a prospect was made in the phosphatic shale in sec. 34, T. 4 S., R. 40 E. (See pl. 7, *B*.) The results of this work are given here for comparison.

Partial section of phosphatic shale in the SE. ¼ SE. ¼ sec. 34, T. 4 S., R. 40 E., Idaho

[Analyst, R. M. Kamm]

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
M-129-16	Clay, sandy, yellow, top not exposed.	*Per cent*	*Per cent*	*Ft. in.*
	Phosphate rock, black, finely oolitic, shattered			1 3
Sample 1	Phosphate rock, brownish gray, somewhat shaly, finely oolitic	28.66	62.7	2
	Phosphate rock, thin bedded, shaly, finely oolitic, shatter zone			2
Sample 2	Phosphate rock, medium oolitic, brownish gray, shaly	25.02	54.6	1 4
	Phosphate rock, shatter zone, brown, shaly fragments			1 10
	Limestone, brown			2½
	Phosphate rock, brownish gray, shaly			3½
Samples 3, 4, and 5.	Phosphate rock, brownish gray, thin bedded, partly shaly, medium to finely oolitic; 3 samples, about 20 inches each.	29.82 24.45 21.73	65.1 57.9 47.4	5 2

Partial section of phosphatic shale in the SE. ¼ SE. ¼ sec. 34, T. 4 S., R. 40 E., Idaho—Continued

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	Per cent	Ft.	in.
Sample 6	Phosphate rock, beds 1½ inches thick, brownish gray, medium to finely oolitic.	33.22	72.5		5
	Phosphate rock, thin bedded, brownish gray, finely oolitic			1	3
	Shatter zone, mostly phosphate				8
Samples 7 and 8.	Phosphate rock, brownish gray, in beds ¼ to ½ inch thick, finely oolitic; 2 samples, 22 inches each.	31.33 30.20	68.3 65.9	1 1	10 10
	Limestone, brown, weathered				4½
Sample 9	Phosphate rock, brownish gray, thin bedded, finely oolitic	28.28	61.8	1	4
	Limestone, dark brownish gray			2	
Sample 10	Phosphate rock, brownish gray, shaly, finely oolitic	28.33	61.8	2	
Sample 11	Phosphate rock, in beds ¼ to 1 inch thick, dark gray, finely oolitic	30.03	65.5		6
	Phosphate rock, brecciated and shattered, weathered almost claylike				7
Samples 12, 13, and 14.	Phosphate rock, black with yellow specks, coarsely oolitic, in beds ¼ to 1 inch thick; 3 samples, about 21 inches each.	32.92 33.34 30.21	71.8 72.7 65.9	5	5
	Phosphate rock, shaly, finely oolitic, and brown shale			1	
	Limestone, gray, top of Wells formation, not measured; strike N. 41° W., dip 62° S.			33	3½

Stratigraphically above the section just given but 138 feet farther down the slope, corresponding to about 112 feet above the highest bed included in the section, is a bed of hard phosphate 10 inches thick, which forms a ledge. Sample 15, taken from this ledge, yielded 20.70 per cent phosphorus pentoxide, equivalent to 45.2 per cent tricalcium phosphate. The phosphatic shale at this locality appears from the above data to be at least 145 feet thick.

The section above described is unusually rich in phosphate, containing at least 31 feet 6 inches of phosphate rock, of which 24 feet 6 inches was sampled and found to average about 63 per cent tricalcium phosphate. One of the richest beds is a few feet above the middle of the trenched portion of the section. It is 1 foot 8 inches thick and averages 72.5 per cent tricalcium phosphate. Another bed just above is thicker but of poorer quality, being 5 feet 2 inches thick and averaging 56.8 per cent tricalcium phosphate. The most important bed commercially is near the base; this bed is 5 feet 5 inches thick and averages 70.1 per cent tricalcium phosphate. Besides these beds there are five others, ranging from 13 inches to 3 feet 8 inches in thickness and from 61.8 to 67.1 per cent (average of samples 7 and 8) tricalcium phosphate.

The shatter zones and the proximity of the fault already mentioned suggest that some of the phosphate beds may be repeated, but the lithologic details above given differ sufficiently to show that there is probably no duplication.

Ten of the samples taken from the trench above described were divided into four sets of composites and tested for iron and alumina. The composite including samples 3, 4, and 5 yielded 0.51 per cent

Fe_2O_3 and 2.56 per cent Al_2O_3. As the combined amount of these two substances present was less than the limit usually allowed (p. 68), the iron and alumina were not separately determined for the remaining composites but were grouped in a single determination for each. The composite including samples 7 and 8 yielded only 1.96 per cent of iron and alumina; the composite including samples 10 and 11, 1.92 per cent; and the composite including samples 12 to 14, 1.19 per cent.

From the data given above it seems safe to assume for purposes of computation that T. 5 S., R. 40 E., contains a bed of workable phosphate at least 5 feet thick and averaging 70 or more per cent tricalcium phosphate. The depth limit of classification for such a bed under current regulations is 4,000 feet.

On the basis of the existing classifications 6,760 acres in this township is reserved as phosphate land. (See fig. 3.) The boundaries of this area, which have to follow public-land subdivisions, include more territory than is needed for the computation of an estimate of tonnage. The actual area so employed is 4,570 acres.

If the weight of a cubic foot of phosphate rock in the ground is assumed to be about 180 pounds, a horizontal bed 5 feet thick underlying 4,570 acres would contain about 79,983,000 long tons. Allowance for the dip of the beds would increase this estimate, but uncertainties of structure, especially the attitude of the Bannock overthrust, may affect it adversely. The estimate as given is believed to be moderate and is therefore retained.

T. 6 S., R. 40 E.

T. 6 S., R. 40 E., overlaps the Henry quadrangle on the east about 2 miles. It includes some of the western foothills of Reservoir Mountain, much of Corral Creek valley, and part of the Chesterfield Range. A road through Corral Creek valley connects the township with Soda Springs between 12 and 15 miles to the south, and with Fort Hall and Blackfoot, 25 miles or more to the northwest. Poor roads, hardly more than trails, cross the Chesterfield Range to Portneuf Valley by way of the divide southeast of Sawmill Creek and up Thompson Creek.

Structural details.—The Woodside shale crops out in the E. ½ secs. 1 and 12, and beds of Wells and Phosphoria in secs. 12 and 13. The western part of the Wells ledge, which constitutes the westernmost exposure of the older rocks in Reservoir Mountain, is brecciated and contains much chert and secondary quartz. There is travertine both north and south of this ledge that suggests faulting. The Rex chert, however, occupies the next knoll south of the Wells along its strike and indicates the presence of an anticline that pitches gently southward. It is inferred that the anticline is broken by a fault that brings in higher beds beneath cover on the west.

A fault that offsets eastward the structure of Reservoir Mountain is believed to enter the township in the northeast corner of sec. 24, but it passes beneath cover and has not been identified farther west. It is known in the Henry quadrangle as the Pelican fault. The eastward displacement of the southern parts of the Rock Creek syncline and the Twentyfourmile anticline may be due to this fault rather than to bending as suggested by the mapping of their axes. The fault in King Creek on the west side of the quadrangle is suggestive in this connection, but the ridge of Carboniferous rocks that crosses the township from sec. 7 to sec. 33 is apparently not offset, and if a transverse fault does cut it the dislocation has not been recognized. However, this relationship was not suspected in the field, and no search for pertinent evidence was made. Reservoir Mountain and the structural features associated with it have been described elsewhere.[46]

The other folds represented in the township, named in order southwestward, are the Nigger Creek syncline, the Grizzly Creek anticline, the Graves Creek syncline, the Twentyfourmile anticline, and the Rock Creek syncline. These folds are so concealed by Tertiary and Quaternary rocks that exposures only here and there are available to show the general position and character of the folds. In drawing the geologic structure section F–G these exposures have been employed in conjunction with the knowledge of the folds as more fully exposed in Tps. 5 and 6 S., R. 39 E., and T. 5 S., R. 40 E.

Phosphate deposits.—The phosphatic shale is exposed in this township only in the SE. ¼ sec. 12 and the NE. ¼ sec. 13. Phosphate is doubtless associated with the Twentyfourmile anticline in secs. 7, 8, and 17 and with the Rock Creek syncline in secs. 30 and 31, as indicated in the structure section F–G. It is estimated that at the line F–G the phosphate beds of the anticline would lie between 500 and 1,000 feet east of the 6,000-foot structure contour in sec. 17. Similarly it is believed that in the Rock Creek syncline the phosphate would lie approximately between the 6,000-foot structure contour lines drawn on the two sides of the axis. In each of these places the position of the phosphate can be determined only by boring or mining operations.

The phosphate of the Rock Creek syncline was prospected by the Geological Survey party in sec. 25, T. 6 S., R. 39 E., where a partial section exposed at least 4 feet of phosphate averaging 66 per cent or more of tricalcium phosphate. (See p. 80.) In 1916 the Geological Survey party prospected the phosphatic shale in the NE. ¼

[46] U. S. Geol. Survey Prof. Paper 152, pp. 34, 164, 1927.

NE. 1/4 sec. 30, T. 6 S., R. 41 E., where a bed of phosphate at least 7 feet thick was found, 5 feet of which contained 70 per cent or more of tricalcium phosphate. It is reasonable to suppose that the phosphate present in T. 6 S., R. 40 E., is not less than 4 feet thick and will average more than 66 per cent of tricalcium phosphate.

The phosphate rock in the Rock Creek syncline and the Twentyfourmile anticline is not considered sufficiently available to classify, because it is so thoroughly concealed and because any development of it must undoubtedly be delayed until other regions where it may be located without boring are exploited. The existing classified phosphate land in this township includes 2,160 acres in secs. 1, 12, 13, 24, and 25. (See fig. 3.) For computing tonnage, however, it has been thought best to limit the area considered to a strip about 0.7 mile wide lying along the township line in secs. 1, 12, 13, and 24, and comprising 1,160 acres. From the above-mentioned data obtained in sec. 30, T. 6 S., R. 41 E., it is assumed that this area is underlain by a 5-foot bed of phosphate, which, on the same basis as previous computations, should yield about 20,300,000 long tons of phosphate rock if horizontal. Allowing an increase of 20 per cent on account of the dip, which ranges from 19° to 40° and is in some places overturned, the partial estimate for the tonnage of this township would amount to 24,360,000 long tons.

T. 7 S., R. 40 E.

T. 7 S., R. 40 E., overlaps the Henry quadrangle about 1 1/2 miles and includes most of the south end of the Chesterfield Range with adjacent portions of Portneuf Valley on the west and the Blackfoot lava field on the east. The range is not crossed by any road here, but the higher parts of it are accessible by trails up most of the canyons. A road through Tenmile Pass gives access from one side of the township to the other at the south. Bancroft, on the Oregon Short Line Railroad about five miles southwest of the township, is the nearest shipping point.

Structural details.—The older rocks of the Chesterfield Range are largely concealed by Tertiary beds. Nevertheless, exposures near the margins afford a fairly satisfactory basis for drawing the geologic structure section, H–I (pl. 2), in which it appears that folds recognized farther northwest continue into this township. Thus with little doubt the Rock Creek syncline and Twentyfourmile anticline are present, and in the northeastern part of the township probably some of the Graves Creek syncline is represented.

Phosphate deposits.—Phosphate is not exposed in the township, but, as suggested by the structure section, it probably underlies an area roughly bounded by the two 6,000-foot structure contours that outline the position of the Rock Creek syncline. It also probably follows the east limb of the Twentyfourmile anticline northwestward from about the NE. ¼ sec. 13. Here, as in T. 6 S., R. 40 E., any actual location of phosphate beds must be determined by boring or by mining operations.

No definite information is available about the character of the phosphate in this township. On the basis of work done in neighboring townships, however, it is believed that the phosphate rock here will prove to be 4 feet or more thick and of 70 per cent quality. The general continuity and uniformity of character of the phosphate throughout the region of which this township forms a part supports this assumption.

There is with little doubt a considerable tonnage of phosphate in the township that may ultimately prove minable. Nevertheless, no land here is classified as phosphate land, and no estimate of tonnage is attempted, because of the extent and thickness of the Tertiary cover and because the probability of exploiting the phosphate is very remote.

GOVERNMENT INVESTIGATIONS RELATING TO PHOSPHATE

The United States Geological Survey and the Bureau of Soils have engaged in phosphate investigations for many years. More recently the Bureau of Standards and Bureau of Mines have also taken up this work.

GEOLOGICAL SURVEY

The Geological Survey has studied the phosphate fields of the country to determine the distribution, character, relative abundance, and workability of the phosphate rock and particularly to obtain data for the classification of public lands. The present report is an example of such a study expanded to include a description and discussion of the geologic features of an entire quadrangle. Other briefer studies involve merely the examination and prospecting of specified tracts of land preliminary to the determination of their legal status or the feasibility of their development under Federal lease. Work of this type has recently been done both in Florida and in the Western States.[47] In addition the Geological Survey has for many years collected statistics and trade notes relating to the phosphate industry, which it has published in the chapters on phosphate rock in the annual volumes of Mineral Resources. Upon the transfer of the division of mineral resources of the Geological Survey to the Department of Commerce, July 1, 1925, this work was assigned to the Bureau of Mines.

[47] See chapters on phosphate rock in Mineral Resources for 1923, issued by the United States Geological Survey, and for 1924, issued by the Bureau of Mines.

BUREAU OF SOILS

For a number of years scientists of the Bureau of Soils, Department of Agriculture, have been experimenting on the volatilization of phosphoric acid from phosphate rock with a view to reducing the cost of extraction. From a brief account of some of these experiments[48] the following excerpt is taken.

> The raw materials used in the volatilization process of preparing phosphoric acid are phosphate rock, sand, and coke. When these are ignited at the proper temperature under reducing conditions, phosphorus is evolved in the elemental state, and it is this process that is now in use for the commercial preparation of this material. If the ignition is made in a type of furnace from which the air is not excluded, the evolved phosphorus is at once oxidized to phosphorus pentoxide and escapes from the furnace as dense white fumes. Owing to the hygroscopic nature of this fume it readily reacts with the moisture of the air or with moisture driven off from the charge and may be readily recovered as a solution of phosphoric acid by passing through a Cottrell precipitator.

The paper discusses the reactions that may occur when calcium phosphate is ignited with silica and carbon either singly or in combination under different temperatures or other conditions.

BUREAU OF STANDARDS

With the cooperation of a number of fertilizer companies the Bureau of Standards, Department of Commerce, in 1924 analyzed its standard phosphate-rock sample No. 56.[49] The work brought out a number of interesting facts concerning the procedure for the determination of moisture, phosphoric acid, and "soluble iron and alumina" by the old methods and resulted in the discovery of desirable changes in these methods as well as the development of certain new methods. Although special attention was paid to the usual determinations just mentioned, methods for the less commonly determined ferric oxide, alumina, and lime were also included.

The recommendations of the authors are summarized as follows:

> The use of boric acid is desirable in preparing solutions for the analysis of phosphate rock, for this lessens the hydrofluoric acid attack on glassware and prevents the interference of this acid in determinations of phosphorus.
>
> Results obtained by solution of the ammonium-phosphomolybdate precipitate and a single precipitation with magnesia mixture can not be correct except through compensating errors, for the precipitate always contains molybdenum and is rarely of ideal composition. If magnesia mixture is added too slowly to neutral or ammoniacal solutions of phosphate the results are usually low. For accurate analyses solution of the magnesium ammonium phosphate precipitate is recommended, followed by the addition of 2 to 3 cubic centimeters of magnesia mixture and reprecipitation by ammonia.

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[48] Ross, W. H., Mehring, A. L., and Jones, R. M., Preparation of phosphoric acid: Jour. Ind. and Eng. Chemistry, vol. 16, pp. 563–566, 1924. See also U. S. Dept. Agr. Bull. 1179, 53 pp., 11 pls., 12 figs., December, 1923.

[49] Lundell, G. E. F., and Hoffman, J. I., The analysis of phosphate rock: Jour. Assoc. Off. Agr. Chemists, vol. 8, pp. 184–206, 1924.

In the alkalimetric method for phosphorus the solution should not be heated after the addition of the molybdate reagent. The 23:1 ratio can not be used in calculating the phosphorus titre of the sodium hydroxide solution unless the method is carefully worked out and followed to the letter.

It is not difficult to get concordant results for "soluble iron." The determination of "soluble alumina," on the other hand, requires rigid attention to a definitely defined method of solution and careful analysis if comparable results are to be obtained.

BUREAU OF MINES

As stated above the Bureau of Mines, Department of Commerce, has taken over the statistical work relating to phosphates and has assumed responsibility for preparing and publishing the annual statements. Requests for these publications should hereafter be addressed to the Director, U. S. Bureau of Mines, Washington, D. C.

COMPARISON OF PHOSPHATE ROCK FROM DIFFERENT FIELDS

Occurrence and physical characteristics.—The Florida phosphate is distinguished from that of the other fields in the United States by its generally lighter color, by the finer texture and more nearly structureless character of individual masses, and by the more common association of bones, teeth, and fragments of replaced shell with the rock. The hard rock is largely a residual accumulation upon an irregular limestone floor of Eocene age, of phosphatic débris gathered by the agencies of solution, secondary deposition, and slumping from phosphatic strata of Miocene age. The direction of concentration has been mainly downward, with little lateral transportation of the phosphate-bearing materials or solutions. The same causes have accentuated the irregularities of the floor on which the phosphate has accumulated. The result is extreme irregularity in thickness and quality of the phosphate-bearing mass or matrix. Only intensive prospecting by drilling can determine the extent, thickness, and quality of the phosphate in any tract of supposedly phosphate-bearing land.

The land pebble is a concentration of phosphate rock by the same processes and from the same sources as the hard rock, with the added features of erosion and redeposition. That is to say, portions of the Miocene phosphate-bearing strata and accumulations of hard rock have both been eroded and redeposited as part of a new group of marine beds of Pliocene age. The floor on which this deposit is laid down is more even and smooth than the floor of the hard-rock deposits. The formation itself is also more evenly distributed through the region in which it occurs. Thus prospecting to determine the character of any particular tract need not be so intensive or expensive as in the hard-rock field. Nevertheless, the distribution of the phosphatic matrix within the formation is decidedly uneven, as regards both thickness and quality, so that careful prospecting must precede commercial development.

In both the hard rock and the pebble fields considerable overburden must be removed, and the matrix includes much clay and sand, together with boulders of limestone and chert, so that thorough washing is necessary to separate the phosphate from its unprofitable matrix. Some soft phosphate is lost by this process, but the washings from the rock as mined are accumulated in worked-out pits, so that some of this material may be recovered later should the market justify the undertaking.

The South Carolina rock is similar to some phases of the Florida hard rock, but it does not have such an irregular base.

The Tennessee brown phosphate is also a residual deposit but generally is of more granular appearance than the Florida rock, and its color is darker, being dark brown or black to yellow. It also has accumulated upon a limestone floor whose inequalities have been accentuated by solution. The several phosphatic formations that have contributed to it are much older than the Florida rock, being of Ordovician age.

The Tennessee blue phosphate is an original marine deposit, corresponding in a way with the land-pebble deposit of Florida. It consists of earlier residual brown phosphate, rearranged and redeposited by the sea, together with some additional phosphatic material that was present in the Devonian or Mississippian waters in which it was laid down. Its texture is finely granular or even oolitic in appearance, and its color is black to dark blue, weathering brown.

The Tennessee brown phosphate must be prospected, mined, and washed in much the same manner as the Florida rock. The blue rock, on the other hand, is mined by underground methods like coal. Unfortunately the bed is rarely more than 3 feet thick and usually less, and much barren material must be moved in order to get the desired phosphate.

The western phosphate rock is much like the Tennessee blue rock in appearance, having a characteristic oolitic texture and a black to brown or grayish color. It is more or less friable, though some beds are hard and dense. It is an original marine deposit, there having been, so far as known, no adequate previous accumulation of residual phosphate, such as was available for rearrangement and redeposition when the Tennessee blue phosphate and the Florida land pebble were laid down. There was, to be sure, a comparatively small and irregularly distributed quantity of phosphate laid down in the beginning of the upper Mississippian, but this is of the same general nature as the Permian deposits and could have contributed little to the widespread and relatively abundant phosphatic accumulations of the later epoch. The western phosphate must be mined like coal, by underground methods, but the productive beds are so thick, usually 5 feet or more, that much of the development work in a given bed can be carried on in the phosphate rock itself. Thus little waste material need be handled. Moreover, the western rock, like the Tennessee blue rock, needs no washing. The rock thus far mined is relatively dry, but some of the producers run it through a crusher and a dryer before shipping in order to command a higher price.

Chemical and mineral composition.—Although the types of phosphate rock from the several fields differ in physical appearance, they are much alike in chemical and mineral composition. So far as optical properties are concerned more attention has been paid to the Florida and western phosphate rock than to material from other fields. Both isotropic and doubly refracting minerals or mixtures of minerals occur in these phosphates. It is thought that the isotropic mineral may be collophanite and that the doubly refracting substances may correspond with one or more of the minerals from the French phosphorites called dahllite, francolite, or quercyite, described by La Croix.[50] The great difficulty in studying the mineralogy of the phosphates is to obtain pure material for each mineral to serve as a standard of comparison.

The following table includes typical high-grade material from each of the more important fields; complete analyses of Tennessee rock are not available.

Analyses of typical phosphate rock from various fields

	South Carolina land rock [a]	Florida		Tennessee		Western field [f]
		Hard rock [b]	Land pebble [c]	Brown rock [d]	Blue rock [e]	
Insoluble	13.03		4.34			2.62
SiO_2		3.44				.46
Al_2O_3	.40	1.49	2.53			.97
Fe_2O_3	1.38	1.43	1.35			.40
MgO	Trace.	.23	.21			.35
CaO	39.10	48.81	47.95			48.91
Na_2O		Trace.				.97
K_2O		Trace.				.34
H_2O	2.43	.90	.63			1.02
H_2O combined		1.98	3.15			1.34
TiO_2		.13				None.
CO_2	3.05	2.71	2.19			2.42
P_2O_5	27.23	35.95	34.72	32.39	30.30	33.61
SO_3	1.45	.10				2.16
F		2.55	2.72			.40
Cl						Trace.
Organic matter	5.68					Not determined.
Undetermined	5.25					
	99.00	99.70	99.79			98.97

[a] U. S. Geol. Survey Bull. 580, p. 196, analysis 4.
[b] U. S. Geol. Survey Bull. 604, p. 72, analysis 6.
[c] U. S. Geol. Survey Bull. 604, p. 80, analysis 38.
[d] U. S. Bur. Soils Bull. 81, p. 9, average of 6 analyses.
[e] U. S. Bur. Soils Bull. 81, average of 8 analyses.
[f] U. S. Geol. Survey Bull. 430, p. 465, analysis 4.

[50] La Croix, A., Sur la constitution minéralogique des phosphorites françaises: Compt. Rend., vol. 150, p. 1213, 1910; Minéralogie de la France, vol. 4, pt. 2, p. 555, 1910. See also Rogers, A. F., Nature and origin of the "brown rock" phosphorites of Tennessee [abstract]: Geol. Soc. America Bull., vol. 39, pp. 279–280, 1928.

Among the interesting comparisons that may be drawn from the above table are the relatively low amounts of silica and insoluble material and of iron and alumina in the western rock as compared with Florida and South Carolina rock. Lime and phosphoric acid are comparable in all except the South Carolina rock. Fluorine is present in both Florida and western rock, but it is less conspicuous in the latter.

PHOSPHATE RESERVES OF THE UNITED STATES

The Government now has two extensive phosphate reserves, one in Florida and the other in the Western States.

FLORIDA

The first phosphate withdrawal in Florida, which included 2,400 acres, was made on July 2, 1910. Further withdrawals, with some subsequent restorations, have since been made, and the total lands withdrawn on November 1, 1928, comprised 67,076 acres, in parcels ranging in size from a fractional subdivision of less than 40 acres to as much as 400 acres and distributed in approximately 295 townships in about 31 counties, extending from Apalachicola River at the northwest as far south as Fort Myers. The belt of country thus included ranges from 10 to nearly 100 miles in width. Only 120 acres in Florida has thus far been classified as phosphate land.

WESTERN STATES

Since December 9, 1908, the Government has maintained a phosphate reserve in a group of Western States. The great bulk of the phosphate-bearing area in these States is public land, though some has passed into private ownership. The acreage of the reserve has changed from time to time in accordance with the results of geologic examinations of the withdrawn lands, but the total has remained large.

Outstanding withdrawn phosphate lands in Western States, Nov. 1, 1928

	Acres
Idaho	391, 532
Montana	279, 944
Utah	301, 945
Wyoming	989, 289
	1, 962, 710

In addition to this land, areas amounting to 160 acres in Utah, 268,299 acres in Idaho, 25,293 acres in Wyoming, and 3,833 acres in Montana, or 297,585 acres in all, have been examined in detail and formally classified as phosphate land. The total classified and withdrawn lands thus amount to 2,260,295 acres. Not all this territory contains high-grade rock, but the estimates given below, which are conservative and incomplete, show that a vast tonnage of high-grade rock may be expected.

Under the act of July 17, 1914, agricultural entries may be made upon withdrawn phosphate lands, but the mineral rights are reserved to the United States.

REVISED ESTIMATES OF TONNAGE

Tonnage estimates of phosphate in the United States have been given in previous reports.[51] There has been some change in the status of the acreage reserved since the publication of the report cited, and the tonnage figures need to be increased by the additional tonnage in western lands classified early in 1925 and decreased by the quantity of rock mined in the several fields in 1925 and 1926 (figures for phosphate rock mined in 1927 not available). The corrected figures are given in the table below.

Estimate of phosphate rock in the United States available December 31, 1926, in long tons

State	Quantity	State	Quantity
Arkansas	20, 000, 000	Idaho	4, 997, 809, 000
Florida	288, 000, 000	Montana	391, 323, 000
Kentucky	878, 000	Utah	326, 745, 000
South Carolina	8, 786, 000	Wyoming	115, 754, 000
Tennessee	83, 018, 000		
	400, 682, 000		5, 831, 631, 000
		Grand total	6, 232, 313, 000

The Government-owned deposits are available for lease under the phosphate provisions of the general leasing law (act of February 25, 1920; Public No. 146). (See General Land Office Circular 696.)

Idaho's position among the phosphate-bearing States is preeminent, but her phosphate resources have as yet hardly been scratched.

FURTHER NOTES ON PHOSPHATE

The annual chapters on phosphate in Mineral Resources of the United States contain many items of interest to phosphate producers. For example, those for 1922–1924 contain, in addition to statistical matter, bibliographies, lists and brief descriptions of patents, accounts of Government investigations, and of commercial processes for treating phosphate rock, together with current notes on foreign phosphate deposits.

[51] See especially U. S. Bur. Mines Mineral Resources for 1924, pt. 2, pp. 87–88, 1925.

LIMESTONE

Limestone is one of the most abundant and widely distributed mineral resources of the Portneuf quadrangle. Its formation was recurrent at intervals from the Cambrian to the Quaternary. There are many textural varieties, and they range in composition from rocks that might be classed as calcareous shale and sandstone to nearly pure limestone. Some beds are well crystallized, but there are no rocks that could be classed as marble.

Earlier Paleozoic limestones.—The exposed earlier Paleozoic limestones are confined to the southwestern part of the quadrangle south of Topons Creek, where they occupy foothills of the Portneuf Mountains, and the southwest flank of the Chesterfield Range between Little Flat Canyon and Tenmile Pass. They occur also in the Soda Springs Hills southeast of Tenmile Pass. These earlier limestones are more or less magnesian, and some of them have been called dolomites. Such are the Fish Haven and Laketown dolomites (pp. 20 and 21), each of which, at localities in the Randolph quadrangle, Utah, contains, according to analyses by W. C. Wheeler, formerly of the Geological Survey, 21.3 per cent magnesia (MgO). The Jefferson limestone, with 19.2 per cent of MgO, is hardly less magnesian.[52]

Limestone probably to be assigned to the early Paleozoic but rated as "high-calcium" was burned prior to 1920 at Pebble, Bannock County, just west of the quadrangle, by the White Elk Lime Co., of Pocatello. Since that date small quantities of limestone from the same property have been sold to sugar factories.

Carboniferous limestones.—The Carboniferous limestones are better adapted for general purposes than most of the others. The Madison and Brazer limestones and the lower part of the Wells formation contain many beds that appear to be relatively pure limestone. The distribution of these formations in the Portneuf quadrangle may be seen by reference to Plate 1. On the whole the Brazer beds appear to be more nearly pure than the others, though this formation includes beds of sandstone and possibly shale in addition to limestone. The Brazer limestone is the source of the lime formerly burned at the limekilns at Montpelier and is locally reported to yield a fine product. An analysis made in the Geological Survey laboratory of an average sample from the Montpelier quarry is given in the following table. The sample represents the 20 feet of thick-bedded, broken, and calcite-seamed rock exposed along the quarry wall.

[52] Analyses cited by Richardson, G. B., Am. Jour. Sci., 4th ser., vol. 36, pp. 406–415, 1913.

Analysis of limestone from quarry at Montpelier, T. 13 S., R. 44 E., Idaho

[W. C. Wheeler, analyst]

Silica (SiO_2)	2.55
Alumina (Al_2O_3)	.43
Iron oxide (Fe_2O_3, total)	.44
Magnesia (MgO)	1.35
Lime (CaO)	51.96
Carbon dioxide (CO_2)	41.08
Loss on ignition less CO_2	1.80
	99.61

As this limestone contains 93 per cent of calcium carbonate the product obtained by proper burning would be classed as high-calcium lime. The ledges of Brazer limestone northeast of Monroe Canyon in T. 7 S., R. 40 E., shown in Plates 3, *A*, and 5, *A*, are very striking topographic features and are readily accessible from that canyon.

Triassic limestones.—The upper beds of the Woodside shale and the lower beds of the Thaynes group locally consist of relatively pure limestone in quantity apparently sufficient for commercial purposes. The localities where these rocks occur, however, are relatively remote from railway transportation and from settlements, though they are easily accessible by roads. No tests or analyses of these limestones have yet been made.

The Portneuf limestone of the Thaynes group has massive beds that are exposed in T. 5 S., Rs. 39 and 40 E., and T. 6 S., R. 40 E., but these are probably too siliceous to have commercial value.

Tertiary limestones.—The Salt Lake formation contains marls and limestones whose commercial value has not been investigated, but some of them might possibly be utilized. Beds of these rocks occur at the narrows of Portneuf River in secs. 15 and 22, T. 5 S., R. 38 E., also in secs. 19 and 30, T. 6 S., R. 40 E., and sec. 10, T. 7 S., R. 40 E. (See also sec. 13, T. 6 S., R. 39 E.)

Quaternary limestones.—The deposits of travertine described on page 37 are also possible sources of commercial limestone. An analysis of such material from Steamboat Spring, on Bear River near Soda Springs, made years ago and cited in Frémont's report,[53] shows 92.55 per cent of carbonate of calcium. This figure suggests that the travertine could supply large quantities of high-grade lime.

ROAD METAL

Supplies of rock suitable for road metal are very abundant in the Portneuf quadrangle, but comparatively little use of them has yet been made. Doubtless as funds become available the standards of

[53] Frémont, J. C., Narrative of an exploring expedition to the Rocky Mountains in the year 1842 and to Oregon and northern California in the years 1843–44, p. 131, London, 1846.

road construction there will be raised. The improvement of the State highway eastward from Pocatello was in progress in 1925 but had not then reached the portion that crosses the southwest corner of the quadrangle. The more accessible materials suitable for road construction are Paleozoic limestone, quartzite, and basalt, all of which are desirable but require crushing. The Rex chert member of the Phosphoria formation, though less accessible, would also serve the purpose well. The weak material from the Thaynes and Woodside formations, which is locally used in many parts of the general region, is available in the northeastern part of the quadrangle. It is, however, better adapted for patching and temporary repairs than for permanent road construction.

BUILDING STONE

None of the rocks exposed in the Portneuf quadrangle have been used to any extent for building, nevertheless some of them may in time prove useful for that purpose. For example, the Brazer limestone contains thick beds of uniform character, relatively free from chert and other impurities, that might be worked into blocks suitable for building. (See pl. 5, *A*.) The rhyolite of the northeastern part of the quadrangle is also suggested as a possibility, though it has not been examined with this use in mind. This rock has been used for building in Pocatello, Blackfoot, Idaho Falls, and Rexburg. Basalt has been used in constructing a few buildings. Thus Loughlin [54] notes that

> The Zion Cooperative Mercantile Institution building at Idaho Falls, built in 1884, has a front entirely of basalt in dressed blocks, with both rock face and finely tooled surface; some blocks are 6 feet long. The stone is of nearly black color and contains several small to large irregularly spaced vesicles. It gives a somber appearance but shows no weathering effects after 30 years of exposure, and door sills where loaded trucks have been passing back and forth have not suffered any noticeable abrasion. Basalt has also been used, and with good effect, in the base of the Methodist Episcopal church at Lewiston, erected in 1907. Here the blocks are mostly small, with rock face exposed.

QUARTZITE

In the southwest corner of the quadrangle there are hills of Swan Peak quartzite favorably situated with respect to transportation both by highway and by railroad. In Bear Lake County this rock has been quarried in Worm Canyon, west of Bear Lake, for road metal. The Swan Peak quartzite is ordinarily rather pure and vitreous and should prove a valuable resource. Pure quartzite may be crushed or ground and used in a variety of ways,[55] such as the manu-

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[54] Loughlin, G. F., U. S. Geol. Survey Mineral Resources for 1913, pt. 2, p. 1379, 1914.
[55] See chapters on silica in Mineral Resources.

facture of pottery, paints, and scouring soaps, as a road filler, as a polisher, as a scouring agent, for "frosting" glass, for chemical and metallurgical use, and for other purposes.

WATER RESOURCES

SURFACE WATER

The surface water of the Portneuf quadrangle is practically all gathered in two streams, Blackfoot and Portneuf Rivers, both of which are tributary to Snake River. A little water is contributed to the Bear River drainage system by Tenmile Creek, but most of this sinks beneath the basalt at or near Tenmile Pass and needs no further consideration here. The Blackfoot and the Portneuf have for a number of years been systematically measured by the Geological Survey in cooperation with the State of Idaho, and four gaging stations were formerly maintained on Portneuf River and Topons Creek within the quadrangle. These have been discontinued. The nearest active station on the Blackfoot is at Rocky Ford crossing, in sec. 11, T. 5 S., R. 40 E., about 200 feet below the wagon bridge below Blackfoot Dam and about 1½ miles east of the northeast corner of the quadrangle. The nearest active station on the Portneuf is at the Oregon Short Line Railroad bridge in sec. 23, T. 9 S., R. 37 E., a quarter of a mile west of Topaz station and 6 miles southwest of McCammon.

Blackfoot River.—Records at the Rocky Ford station have been obtained continuously since July 15, 1908. Those for the 10-year period 1914–1924 are summarized in the following table.[56] For details the reader is referred to the reports cited.

Maximum, minimum, and mean annual discharge and annual run-off of Blackfoot River, Rocky Ford station, years ending September 30, 1914 to 1924

Year	Discharge (second-feet)			Total run-off (acre-feet)	Year	Discharge (second-feet)			Total run-off (acre feet)
	Maximum	Minimum	Mean			Maximum	Minimum	Mean	
1914	--------	29	299	216,000	1920	1,120	8.2	201	146,000
1915	1,060	44	408	295,000	1921	1,190	9	220	160,000
1916	928	35	290	210,000	1922	1,010	17	360	261,000
1917	799	3	247	179,000	1923	1,010	22	308	223,000
1918	750	23	259	188,000	1924	936	6	193	140,000
1919	--------	17	251	182,000					

The maximum recorded daily discharge during this period was 1,190 second-feet, in May, 1921, and the minimum was 3 second-feet, in May, 1917. The flow of the river is regulated by the Blackfoot River Reservoir, in the adjacent Henry and Cranes Flat quadrangles.

[56] Compiled from U. S. Geol. Survey Water-Supply Papers 393, 413, 443, 463, 483, 513, and 533, and from Idaho Dept. Reclamation First, Second, and Third Bienn. Repts.

The Blackfoot receives only one unnamed tributary of small volume between the reservoir and the place where it enters the Portneuf quadrangle. Within the quadrangle it is joined by Corral and Nigger Creeks. These streams have not been measured, but their combined flow would total perhaps 25 to 50 second-feet, making the mean annual discharge of the river as it leaves this quadrangle probably about 300 second-feet.

Portneuf River.—The principal stream of the quadrangle is Portneuf River, which enters at the northwest corner, traverses the western part, and leaves at the southwest corner. Its waters are impounded in Portneuf Reservoir. (See p. 105.) Three gaging stations were maintained for a time on Portneuf River within the quadrangle and one on Topons Creek, a tributary, a short distance west of the quadrangle. The records of these stations are summarized below, and in addition the record of the station at Topaz previously mentioned is given.[57]

The first station was on Portneuf River at Faulkner's ranch, just above the ford near the ranch house, about 7 miles northwest of Chesterfield. Incomplete measurements are available from April 28, 1912, to September 30, 1913.

Annual discharge of Portneuf River above reservoir northwest of Chesterfield, Idaho

Period	Discharge (second-feet)			Total run-off (acre-feet)
	Maximum	Minimum	Mean	
1912 (Apr. 28 to Sept. 30)	66	10	24.7	7,510
Oct. 1, 1912 to Sept. 30, 1913	131		17.7	12,800

The second station was in sec. 30, T. 6 S., R. 39 E., about a quarter of a mile below the dam, where a small flume crosses the river, and about 2½ miles from Chesterfield post office. The flow as measured is somewhat greater than that of the river itself because some of the water from Topons Creek is diverted into the reservoir. The results of measurements for the years 1912 to 1915 are summarized in the following table:

Annual discharge of Portneuf River below the reservoir near Chesterfield, Idaho, for the years ending September 30, 1912 to 1915

Period	Discharge (second-feet)			Total run-off (acre-feet)
	Maximum	Minimum	Mean	
1912 (May 23 to Sept. 30)	44	2.6	12.0	2,390
1913	46	3.3	8.99	6,500
1914	81		13.35	9,311
1915 (station discontinued Apr. 9)	7.1	1.5	4.32	1,650

[57] See papers cited in footnote 56; also Water-Supply Papers 292, 312, 332, and 362–B.

The station on Topons Creek was situated in sec. 34, T. 6 S., R. 38 E., at the Butterfield ranch, about half a mile below the head of the diversion canal into Portneuf Reservoir and about 7 miles west of Chesterfield. The record is summarized in the next table.

Discharge of Topons Creek west of Chesterfield, Idaho, for the years ending September 30, 1912 to 1914

Period	Discharge (second-feet)			Total run-off (acre-feet)
	Maximum	Minimum	Mean	
1912 (May to Sept. 30)	355	12	96.3	29,200
1913	162		30.5	22,000
1914 (station discontinued Nov. 6)	220		41.7	30,100

The third station on the Portneuf was situated at W. A. Gamble's ranch, in sec. 26, T. 7 S., R. 38 E., about 3 miles north of Pebble post office and was established September 8, 1910. Its record is summarized as follows:

Annual discharge of Portneuf River near Pebble, Idaho, for the years ending September 30, 1910 to 1913

Period	Discharge (second-feet)			Total run-off (acre-feet)
	Maximum	Minimum	Mean	
1910 (Sept. 8-30)	66	39	47.6	10,970
1911	624	32	98.6	71,300
1912	365	39	93.6	68,000
1913 (station discontinued Aug. 15)	537	34	89.6	57,800

The location of the station at Topaz is given on page 99. Its record is summarized in the following table:

Annual discharge of Portneuf River at Topaz, Idaho, for the years ending September 30, 1913 and 1914, and 1920 to 1924

Period	Discharge (second-feet)			Total run-off (acre-feet)
	Maximum	Minimum	Mean	
1913 (Jan. 12 to Sept. 30)	902	128	233	123,000
1914	770	163	292	211,000
1919-20 (July 20, 1919, to Sept. 30, 1920)	853	152	227	165,000
1921	771	160	279	202,000
1922	822	168	260	188,000
1923 (Apr. 1 to Sept. 30)	562	190	310	112,000
1924	605	121	205	149,000

The records of flow of Portneuf River differ in completeness and in accuracy. From the records given in the reports cited it appears that the Portneuf enters the quadrangle as a small stream with a mean annual discharge of about 20 second-feet. At the reservoir there is some gain from waters diverted from Topons Creek, but there are losses into irrigation ditches just above and below the dam, so that the resulting flow is somewhat less than the volume of the river above the reservoir. Additional water enters below the dam, however, from Topons Creek, which is a tributary twice or three times the volume of the upper Portneuf, and possibly some water enters from Smith and King Creeks, but these streams together with Topons Creek are largely diverted for irrigation. Farther south the flow of the river is considerably augmented by springs. (See pp. 5, 12, and 103.) Thus at the station near Pebble its volume is four or five times as large as where it enters the quadrangle. Beyond the quadrangle the river receives further contributions from tributaries and springs, and there are few significant diversions until it reaches the vicinity of Topaz, where several large canals receive water from it. At this station the river has been increased in volume ten to fifteen times and is nearly as large as the Blackfoot at Rocky Ford station.

GROUND WATER

GENERAL DISTRIBUTION AND AVAILABILITY

No special study of the ground-water conditions in the quadrangle was made, but the supply is believed to be well distributed and probably sufficient to meet the domestic needs of a considerably greater number of residents than are now living there.

In the mountainous parts of the area the rocks are folded and faulted, and the ground-water conditions are correspondingly complex. The water-bearing beds are fractured or dislocated so that the water is returned to the surface at many places in the form of springs. The location of springs with regard to lines of faulting is in some places very striking, as, for example, the spring in the East Fork of Twentyfourmile Creek or possibly the springs that built the travertine deposits at the mouths of Little Flat and Eighteenmile Canyons. Elsewhere the connection of springs with structure lines is not so obvious and their occurrence may be due to other causes. The relatively large number of permanent streams within the mountains bears witness to the presence and wide distribution of ground water there.

The valleys of Blackfoot River and Corral Creek at the northeast are underlain by basalt and have as yet no wells within the limits of the quadrangle. The position of the water table is not known, but the course of Corral Creek suggests that it may be relatively shallow near the bases of the hills and may slope gently northeastward to a maximum depth indicated by the surface of Blackfoot River. Thus the water table might range in depth from 25 to 150 feet. These figures are comparable to those of many wells in Tps. 7 and 8 S., Rs. 41 and 42 E., records of which are available at the Geological Survey.[58]

The basalt-covered part of Portneuf Valley is in large measure dependent upon ground water for its supplies both for domestic use and on the farm. So far as known the supplies available for these purposes are adequate. A considerable number of wells are in use, but their logs are not available for this report. In the area mapped as alluvium the water table is relatively near the surface. This area consists almost entirely of meadow land, considerable parts of which are marshy.

SPRINGS

General character and distribution.—The springs of the Portneuf quadrangle are widely distributed and as a rule are not characterized by unusual thermal conditions or mineral content. A few are of sufficient size to give rise at once to considerable streams. Among these are the Dairy Springs, in the SW. 1/4 SE. 1/4 sec. 31, T. 5 S., R. 40 E., tributary to Grizzly Creek, the spring in the center of the SW. 1/4 sec. 10, T. 6 S., R. 39 E., which supplies much of the flow of Twentyfourmile Creek, and the springs along Portneuf River southwestward from secs. 19 and 20, T. 7 S., R. 39 E., which greatly increase the flow of that stream. These springs have not been measured to determine their discharge, but probably none of them, except possibly some of those along the Portneuf, flow more than 20 second-feet.

Mineral springs.—A few of the springs of the quadrangle should be classified as mineral springs because of the deposits of calcium carbonate that they have made in the past and are to a certain extent still making. The most conspicuous accumulations of travertine, composed chiefly of calcium carbonate, are those at the mouths of Eighteenmile and Little Flat Canyons, described on page 9. These are not now identified with any active spring. On the other hand, the travertine area near the forks of Twentyfourmile Creek is probably still in the process of deposition. The main source of the water is the spring in sec. 10, T. 6 S., R. 39 E. The travertine area begins a short distance below this spring, and the waters are divided by the travertine into interlacing streams. The proximity of this spring to the place where the arched plane of the Bannock overthrust crosses the canyon points to a probable causal relation between the fault and the spring. In the NE. 1/4 sec. 16 another group of springs issues from the hillside and by interlacing streams contributes both to the accumulation of the travertine and to the flow of the creek. No fault has been recognized here, but the spring water issues from beds of the Salt Lake formation, which conceal the underlying structure.

[58] Unpublished report by H. T. Stearns.

An interesting and somewhat conspicuous spring is situated in the SE. ¼ NW. ¼ sec. 15, T. 5 S., R. 40 E., on the north side of Blackfoot River. (See pl. 7, *A*.) This spring has built a cone about 12 feet high and 75 feet in diameter. It has a crater about 13 feet in diameter and 33 feet deep as determined by sounding. The water, which fills the crater, is carbonated and foul from decaying algae. Its temperature is cool but was not measured.

Thermal springs.—No sharp line can be drawn between mineral and thermal springs, for those described as mineral may once have been thermal and those described as thermal have usually some readily recognizable mineral constituents. It is convenient, however, to distinguish as thermal those springs which still have water with temperature noticeably warm or higher than that of most of the springs of the surrounding country. Possibly the spring in sec. 15, T. 5 S., R. 40 E., just described, might better have been included here. There is, however, one distinctly thermal spring in the quadrangle that deserves mention. This is commonly known as Richey's Hot Spring and is situated on the north side of Portneuf River near the center of sec. 34, T. 7 S., R. 38 E., at the contact of the limestone and the basalt. The water feels comfortably warm and is carbonated but does not contain noticeable amounts of sulphur or iron. No samples were collected for analysis. The spring has been walled in to form a pool a few feet across. Diagonally across the river to the southeast is a spring of clear cold water issuing from the basalt. The two springs, though relatively near each other, are obviously supplied by different sources, the thermal spring doubtless representing some deep fracture or possible fault not otherwise recognized.

UTILIZATION OF WATER

DOMESTIC USE

Settlers along the foothills or in the alluvial parts of Portneuf Valley obtain their water for domestic use from surface bodies or shallow wells. In the basalt-covered area dependence must be placed on wells presumably somewhat deeper. So far as known the supply of ground water for this purpose is adequate.

IRRIGATION

Practically all the streams that enter Portneuf Valley are utilized extensively for irrigation. Their diversion provides sufficient water for irrigating most of the lands lying immediately along the foot slopes of the hills, but the supply is inadequate for large areas throughout the valley. Under these conditions much of the land in Portneuf Valley and southward is at present suitable only for dry farms. Two irrigation projects have been initiated, one of which has been operative for many years but affords little relief for lands within the Portneuf quadrangle; the other is as yet undeveloped. These are respectively the works of the Portneuf-Marsh Valley Irrigation Co. and the project of the Empire Irrigation District.

Portneuf-Marsh Valley works.—According to unpublished information available in the files of the Geological Survey, a mutual association known as the Portneuf-Marsh Valley Irrigation Co. was organized June 22, 1908, to build a reservoir and canal system to irrigate land in the vicinity of Downey, Idaho. Except minor lateral canals the projected works were practically completed March 1, 1912, and on March 20, 1915, the system was turned over to the Portneuf-Marsh Canal Co. for operation. The area irrigable under the project includes a total of 15,600 acres, of which more than 11,000 acres was patented to the State under the Carey Act on March 29, 1918.

The reservoir included in this project, part of an intake canal from Topons Creek, and part of the outlet canal are shown on Plate 1. The reservoir is created by a dam 50 feet high across Portneuf River in sec. 24, T. 6 S., R. 38 E., and sec. 19, T. 6 S., R. 39 E. It has a storage capacity of 28,000 acre-feet and a surface area at high-water line of 1,500 acres. It is 35 miles above the point of diversion of the company's main canal measured along the general course of the valley. Many small ditches divert water from the river below the reservoir, but the larger canals are located between McCammon and Dempsey. The discharge at Topaz, 1¼ miles above the diversion canal of the company, represents the water available for this company and for the other companies below.

Empire Irrigation District.—The Empire Irrigation District was organized about 1923 with headquarters at Bancroft, Idaho, for the purpose of irrigating between 35,000 and 55,000 acres of land in Tps. 6, 7, and 8 S., Rs. 38, 39, and 40 E. It is proposed to divert water from Blackfoot River by means of a tunnel 3,820 feet long near Morgan Bridge, in sec. 19, T. 4 S., R. 39 E., in the Paradise Valley quadrangle, and to lead it by canal southward along the east side of Portneuf Valley and adjoining territory to a point in sec. 30, T. 9 S., R. 40 E., a distance of about 32 miles in a direct line south-southeast from the diversion point but several times greater if measured along the right of way of the proposed canal. The project also includes the diversion of water from Blackfoot River in sec. 14, T. 7 S., R. 42 E., and the use of reservoir sites in the Fivemile Meadow district in T. 8 S., Rs. 41 and 42 E., for the irrigation of additional lands in Tps. 8 and 9 S., Rs. 41 and 42 E. The surplus waters of the eastern areas are to be available for the western areas by a connecting system of ditches.

As the water of the Blackfoot is practically all appropriated, its use by the Empire Irrigation District is contingent upon the purchase by that district of 110,000 acre-feet of storage in the reservoir at American Falls constructed by the United States Bureau of Reclamation. This storage supply will then be exchanged for an equal quantity of storage in Jackson Lake Reservoir, which will be utilized to obtain the release of Blackfoot River water for the Empire district. Plans and surveys had been completed, rights of way obtained, and an allotment of the required storage capacity in the American Falls Reservoir had been obtained, but at the time of writing (April, 1926) the financing necessary for the purchase of this desired storage had not been arranged. The location of the right of way for the canal in Portneuf Valley within the limits of the quadrangle is shown on Plate 1.

The soil is good, consisting in part of volcanic ash and in part of alluvium. The growing season, however, is relatively short, the average being only about 65 days, as indicated by records of the United States Weather Bureau at Chesterfield. The mean annual rainfall there is 13.74 inches (p. 12). These meteorologic conditions indicate that dry-farm crops can be raised without irrigation during years when the growing season is unusually long. The section is fairly well settled, and the chief crops produced are hay and grain. With an adequate water supply for irrigation, sugar beets probably could be grown successfully in most years.

WATER POWER

Blackfoot River.—Power-site reserves have been located along Blackfoot River in T. 5 S., R. 40 E., partly in the Portneuf quadrangle. This section of the river lies in a canyon which has a low gradient [59] and other physical features unfavorable to the development of water power. Furthermore, the operation of the Blackfoot Reservoir immediately above causes abrupt changes in the stream flow. For about 10 per cent of the time the flow is 15 second-feet or less, and the 10-year average for the months November to March, inclusive, a period during which under present market conditions the demand for power is high, was only 85 second-feet. These conditions make the potential power of the Blackfoot in this quadrangle of little commercial importance. The same is true of the section farther downstream, where other physical conditions of the river are materially more favorable to power development.

The lands suitable for power sites have been reserved for the purpose of maintaining the interest of the public in the development of water power, and the Federal Power Commission is authorized

[59] Unpublished reports of Ralf R. Woolley and W. G. Hoyt.

to issue licenses for such development on terms designed to protect the public interests.

Portneuf River.—As stated by Heroy,[60] Portneuf River in the upper part of its course flows through a broad marshy valley with slight fall. The discharge is small, and no feasible power sites are recognized within the limits of the Portneuf quadrangle. After leaving the Portneuf quadrangle the river has, in many places, a steady gradient and affords opportunity for the development of a small amount of power in the section between Pebble and Pocatello. West of Pocatello the river has only a slight fall. The normal flow during the irrigation season is largely diverted, and as the Portneuf Reservoir of the Portneuf-Marsh Valley Irrigation Co. stores much of the winter flow, the possibility of developing power on the lower portion of Portneuf River is unattractive.

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[60] Heroy, W. B., Water resources of the Fort Hall Indian Reservation: U. S. Geol. Survey Bull. 713, p. 148, 1920.

6148—29——8

INDEX

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